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**EXPERIMENTAL
PLANT PHYSIOLOGY**

EXPERIMENTAL PLANT PHYSIOLOGY

FOR BEGINNERS

BY

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PREFACE

IN this book the main physiological facts of plant-life are connected together by a series of simple experiments, all of which can be carried out without the use of any elaborate apparatus. As far as possible the inferences obtained in the working of one experiment form the starting-point for the next.

The book is intended essentially as a guide to practical work, and every experiment should therefore be carefully worked through, not merely read. The best plan for a teacher to follow, in all physiological work, is to present a problem to the children, and encourage them to suggest the method by which it may be solved and to draw their own conclusions from the observations made.

By a Standing Order of the London County Council, it must be stated that the Council accepts no responsibility for the opinions or conclusions given in this book.

L. E. C.

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EXPERIMENTAL PLANT PHYSIOLOGY

SECTION I

THE FOOD OF THE PLANT

CHAPTER I

I. THE COMPOSITION OF THE SOIL

Introductory.—The fact that as a plant develops it increases in weight, is one that needs no demonstration. The oak tree is obviously heavier than the acorn from which it grows. This increase in weight must have been caused by absorption of food-material on the part of the plant. Now the only available sources from which a plant can absorb food are the soil and the air. It is necessary to determine, therefore, whether the plant takes in food from one or both of these sources, and, further, what is the nature of the food taken in.

The Composition of the Soil.—The soil is composed of grains formed from the breaking down of rocks, together with a varying amount of humus or decaying animal and vegetable matter. The particles are loosely held together, and the spaces between are filled with air and water.

As a great many of the substances contained in the soil are soluble in water they pass into solution; thus the water ceases to be pure and becomes a solution of various salts.

An analysis of this solution is beyond the scope of this book, and we must be content to use the results given to us by chemists.

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The following is a list of the more common salts dissolved in the water of the soil:

Common table salt, made up of sodium and chlorine.		
Gypsum	„ „	calcium, sulphur, and oxygen.
Epsom salts	„ „	magnesium, sulphur, and oxygen.
Glauber's salts	„ „	sodium, sulphur, and oxygen.
Traces of chlorides, nitrates, and phosphates of calcium, magnesium, and potassium	} „ „	{ chlorine, nitrogen, oxygen, phosphorus, calcium, magnesium, and potassium.

From this list it appears that the substances present (called by the chemist "elements") are: sodium, chlorine, calcium, magnesium, sulphur, oxygen, nitrogen, phosphorus, and potassium.

It must be remembered that these are the more common elements present in solution in the soil, but they are not the only ones that may be present; for instance, the important element, carbon, is often there. It is a compound of carbon, calcium bi-carbonate, that causes the "hardness" of water in limestone districts. But, as it will be shown later, carbon compounds in the soil are not necessary for plant-life. A plant thrives just as well in a soil that contains no carbon as in one in which this element is present.

In the soil, then, certain substances are present that are available as food. By a series of simple experiments it is possible to find out how far these substances are made use of in the feeding-processes of the plant.

II. THE ABSORPTION OF FOOD FROM THE SOIL

In the working of any experiment there are four distinct steps that have to be considered. In the first place it is necessary to formulate a definite aim. After

this some method of tackling the problem must be evolved. Next, all observations made should be carefully recorded. Lastly, the facts gathered from the observations must be set down in order.

These steps may be written thus :

- Step 1. What it was desired to find out.
- Step 2. What was done.
- Step 3. What was seen.
- Step 4. What was learnt.

Or, expressed more briefly :

- Step 1. Aim.
- Step 2. Method.
- Step 3. Observations.
- Step 4. Inferences.

EXPERIMENT 1

Aim.—To determine whether a plant absorbs water.

Method.—A bean seedling or a daffodil bulb is grown in a jar of water. The surface of the water is covered with greased cardboard or tin-foil, to prevent loss through evaporation. The level of the water is marked.

Observation.—As the plant grows the water gradually decreases.

Inference.—Water must have been taken up by the roots that are in it. Thus: *The root of a plant absorbs water.*

EXPERIMENT 2

Aim.—To determine whether parts of the plant, other than the roots, can absorb water.

Method.—Three well-grown bean seedlings or other small potted plants are used. The first is watered regularly in the usual way. The leaves and stem only of the second plant are watered; to this end the whole of the pot as well as the soil should be carefully covered with tin-foil during the process of watering; the tin-foil must be removed between the periods of watering,

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otherwise air also will be prevented from reaching the roots. The third plant is left unwatered.

Observations.—The first seedling thrives. The second and third die.

Inference.—The life of a plant cannot be maintained unless water is supplied to the roots. Thus: *The root is the absorbing organ of the plant.*

(*Note.*—This experiment applies only to land plants; in submerged aquatic plants absorption takes place over the entire surface. It must also be remembered that a *cut* stem is able to absorb.)

EXPERIMENT 3

Aim.—To determine the rate at which a plant is absorbing water and the external conditions by which the rate is affected.

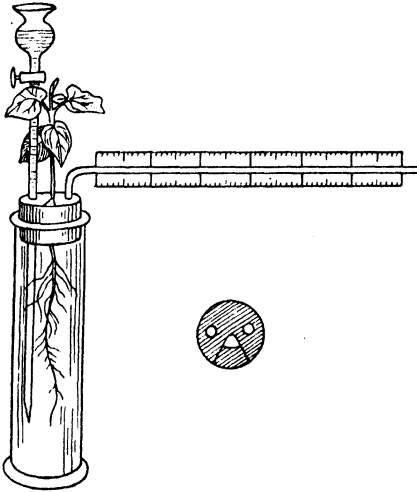


FIG. 1

Method.—The pieces of apparatus needed in this experiment are a glass flask or gas-jar with cork to fit, a thistle-funnel with a tap, a piece of very narrow glass-tubing, a thermometer, and a well-grown potted plant with a woody stem that will not easily be injured.

The glass-tubing is bent at right angles so that the long arm measures at least 15 inches. The length is marked off in inches by means of strips of gummed paper or a cardboard scale.

The thistle-funnel, the glass-tubing and the plant are then fitted into the cork.

To insert the plant it is well to cut a wedge-shaped piece out of the cork, fit the stem into the gap, cut off the angular end of the wedge and replace the remainder (Fig. 1).

The glass vessel is then filled with water and the cork inserted.

After this the thistle-funnel also is filled with water, and the tap is then carefully turned until water fills the whole apparatus, including the bent tube. Great care must be taken that no air is left in the apparatus. The expulsion of air is facilitated if the short arm of the narrow glass-tubing does not project beyond the bottom of the cork.

All connections must now be made air-tight. To this end a little paraffin-wax is melted in a porcelain evaporating dish. The paraffin should be allowed to cool until it is just setting, then it must be put over all the fittings of the apparatus and worked in well with the fingers. This method will be found cleaner and more effective than the pouring of melted paraffin over the joins. It will also prevent possible injury to the plant from the use of paraffin that is too hot. The beginner will often find it difficult to get a piece of apparatus air-tight; if all the corks are soaked for a little while in melted paraffin before being used this difficulty is greatly lessened. Plasticine, instead of or in addition to paraffin, can often be used with advantage in making difficult fittings air-tight.

Observations.—Mark the time taken for the water to be absorbed through a measured portion of the tube. Then refill the tube by means of the tap. Take at least two more readings and record the time taken in each case. If the observer wishes, the actual volume of water absorbed in a given time can be calculated from the formula $\pi r^2 h$ (where $\pi = 3.14$, r = radius of tube, h = length of tube).

It is more important, however, to compare the rates of absorption under different conditions. Thus:

1. Remove the apparatus to the coldest place

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possible. If ice is available the flask should be packed round with it. Take readings.

2. Take readings when the apparatus is warmed.

3. Compare the amount of absorption when the apparatus is in a windy place where the atmosphere is consequently drier.

4. Take readings when solutions of gradually increased strength are substituted for water.

The following is an account of an actual experiment made with the apparatus shown in the photograph

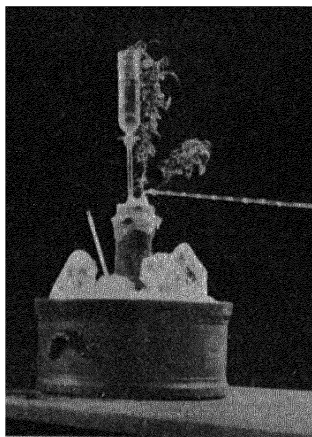


FIG. 2

(Fig. 2). A fuchsia plant was used and this proved very satisfactory, as it was hardy enough to withstand the various changes that it had to undergo during the course of the experiment. To make successful records a great deal of time and patience are necessary. One constant source of difficulty is the recurring leakage of the apparatus caused by varying contractions and expansions when the temperature is changed. This cannot be avoided, and therefore, as soon as a leak occurs, the fittings must be waxed again. The time

given in every case is that taken by the water to move along one inch of the measured glass-tube.

Thursday, May 1st. Dry, windy day. Temp. 13° C.

Readings.	Intervals.
A.M.	
10.57	
11.10	13 min.
11.25	15 "
11.38	13 "
11.50	12 "
	Average, 13·25 min.

Ice was then packed round the jar as shown in the photograph. It was at once seen that the contraction of the water due to cooling would upset any readings made for a considerable time. The apparatus was therefore left until the following morning. Most of the ice had then melted and the temperature of the water was kept at 0° C. by the addition of lumps of ice at intervals. It was assumed that by this time the temperature of the water inside the jar was constant. (More accurate readings could perhaps have been obtained by placing the thermometer inside the gas-jar, but this would have necessitated still another fitting to be kept air-tight.)

It was necessary to re-wax the apparatus.

Friday, May 2nd. Dry, windy day. Temp. 0° C.

Readings.	Intervals.
P.M.	
1.57	
2.26	29 min.
2.51	25 "
3.20	29 "
3.48	28 "
	Average, 27·75 min.

The apparatus was then left with the surrounding water so that it might, with as little harm to the plant as possible, very gradually regain the normal temperature.

Further readings were then taken.

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Monday, May 5th. Wet, still day. Temp. 13° C.

Readings.	Intervals.
A.M.	
9.57	
10.17	20 min.
10.37	20 "
10.56	19 "
11.15	19 "
	Average, 19.5 min.

The apparatus was then heated to 20° C. This was done by placing it in a 7 lb. jam-jar containing water at 30° C.; the water was allowed to cool until it reached 20° C. and was then kept at this latter temperature by the addition of small quantities of hot water. Readings could not be taken for some time owing to the expansion of the water inside the gas-jar. As soon as the temperature inside was constant, records were made.

Afterwards the apparatus was heated to 30° C., and then to 40° C. by the same method.

The whole day continued still and wet.

	Readings.	Intervals.
At 20° C.	P.M.	
	1.7	
	1.23	16 min.
	1.38	15 "
	1.52	14 "
	2.8	16 "
		Average, 15.25 min.
At 30° C.	P.M.	
	4.0	
	4.10	10 min.
	4.19	9 "
	4.30	11 "
	4.40	10 "
		Average, 10 min.
At 40° C.	P.M.	
	5.38	
	5.45	7 min.
	5.50	5 "
	5.56	6 "
	6.2	6 "
		Average, 6 min.

It was not considered desirable to raise the temperature further lest the roots should become injured. The apparatus was then left to regain, gradually, the normal temperature.

On the following day differences in the rate of absorption, due to varying strengths of the solution absorbed, were tested.

A strong solution of common salt was made up; 50 c.c. of this solution was then added to the water through the thistle funnel. A reading was taken. A second 50 c.c. was then added, and another reading taken. By the continuation of this process the strength of the solution inside the jar was gradually increased.

As it was necessary to make allowance for the decreasing vitality of the plant due to the continued experiment, two readings under normal conditions were first taken.

Tuesday, May 6th. Dry, not windy. Temp. 13° C.

	Readings.	Intervals.
Water.	10.20 A.M.	
Water.	10.52 "	32 min.
50 c.c. salt solution added.	11.22 "	30 "
100 " " "	11.58 "	36 "
150 " " "	12.38 P.M.	40 "
200 " " "	1.22 "	44 "
250 " " "	2.12 "	50 "
300 " " "	3.8 "	56 "
350 " " "	4.4 "	56 "
400 " " "	5.8 "	64 "
	6.28 "	80 "

Inferences.—The rate of absorption is affected by external conditions. It increases with rise of temperature; it also increases as the dryness of the surrounding air increases. It is decreased by fall of temperature, and by an increase in the strength of the solution absorbed.

(*Note.*—Had the apparatus been still further heated it would have been found that, after a certain temperature was attained, the rate of absorption again began to decrease.)

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Having now proved that a root absorbs water, it must next be determined whether other substances are absorbed with the water; and, if so, what kind of substances can be absorbed.

EXPERIMENT 4

Aim.—To determine the class of substances that a root can absorb.

Method.—Two coloured substances are chosen so that any absorption that takes place may readily be seen by the change of colour that the plant thereby undergoes. Powdered eosin and powdered carmine are suitable for the purpose, as they are both bright red in colour. A small quantity of these substances is put respectively into two test-tubes and well shaken up with water. The eosin dissolves. The carmine simply remains suspended in the water; it is a very finely divided powder and does not, therefore, quickly settle at the bottom.

A broad-bean seedling is then placed in each test-tube so that its roots are in the liquid.

Observations.—The seedling whose roots are in eosin soon becomes red all over; the colour of the other seedling remains unaltered.

Inferences.—*The root can absorb substances that are soluble, but it cannot absorb insoluble substances.*

(*Note.*—This experiment can be amplified by the use of other coloured substances of each class. It should be noticed that no account is taken here of the absorption of gases, which is reserved for another place.)

The broad deductions drawn from Experiment 4 appear, on further thought, to need some amplification.

It has been proved that a plant cannot absorb a substance unless it is dissolved, yet it is well known that marble is often corroded by the growth of roots upon it, and marble is not soluble in water. Does the root exude something which dissolves the marble? It

seems that there is some solvent in a root which acts on substances that are not soluble in water.

If a little hydrochloric acid be poured over a piece of marble, effervescence will be noticed and the marble will slowly dissolve away, thus showing that some substances that are insoluble in water dissolve in the presence of an acid.

It is possible, quite simply, to find out whether there is present in a root an acid by means of which an insoluble substance, such as marble, may be dissolved.

EXPERIMENT 5

Aim.—To determine whether any acid is present in a root.

Method.—(a) Using litmus solution.

Litmus solution is blue in colour, but turns pink on the addition of a drop of acid.

Fill two test-tubes with a weak solution of litmus. Into the mouth of one put a broad-bean seedling with a radicle of about an inch in length.

(b) Using litmus paper.

Litmus paper also changes colour. Alkaline litmus paper is blue, and becomes red when brought into contact with an acid; similarly, acid litmus paper will be changed from red to blue in presence of an alkali.

A cylindrical gas-jar is lined with a piece of blotting-paper, and the paper is then made thoroughly damp.

A soaked broad-bean and some strips of blue litmus paper are inserted between the glass and the blotting-paper. One strip of the litmus paper is arranged so that the growing radicle will come into contact with it.

Observations.—(a) After a day or two the colour of the solution in which the bean root is growing has become pink; the other solution remains unchanged in colour (Fig. 3).

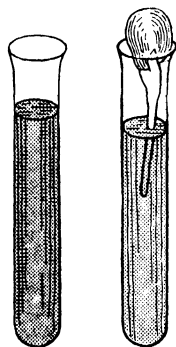


FIG. 3

Blue colour is denoted by darker tint, pink by lighter tint.

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(b) As the radicle grows the piece of litmus paper touched by it gradually turns red; the other strips remain unchanged.

Inferences.—The root contains an acid which, to some extent, passes from it into the surrounding water.

As a result of this acid-exudation, the root can absorb, in addition to substances soluble in water, those substances in the soil that will not dissolve in water alone, but are soluble in the acid that the root gives out.

Growth in Culture Solutions.—It has already been stated (page 1) that the soil is made up of solid particles loosely held together, the spaces between them containing air and mineral solutions.

It is now seen that the plant can feed only on the solutions, since it cannot absorb solid particles however fine they may be.

In order to determine whether all the soluble substances present in the soil are really necessary to plant-life a series of experiments can be made by growing seedlings in various solutions. Such solutions are termed Culture Solutions; one that contains all the soluble salts commonly found in the soil, in the proportion in which they are present, is termed a Normal Culture Solution. Such a solution may be made up as follows:

1000 c.c.	Water	made up of	Hydrogen and oxygen.
1 gramme	Potassium nitrate	„	Potassium, nitrogen, and oxygen.
·5 „	Calcium sulphate	„	Calcium, sulphur, and oxygen.
·5 „	Magnesium sulphate	„	Magnesium, sulphur, and oxygen.
·5 „	Calcium phosphate	„	Calcium, phosphorus, and oxygen.
·5 „	Sodium chloride	„	Sodium and chlorine.
A trace	Iron sulphate	„	Iron, sulphur, and oxygen.

If the elements in this list are compared with those given in the table of soluble salts in the soil (page 2) it will be seen that they are all included here.

A series of seedlings should be grown, one in a normal culture solution, one in a culture solution with potassium omitted, another in a solution with calcium omitted, and so on: in every case one of the elements should be omitted and all the others included. By this means it is possible to see which of the elements are actually necessary for the full development of the plant.

All this is simple enough in principle, but, unfortunately, the experiments are not easy to carry out. Very large vessels are needed for the solutions, and they are only with great difficulty kept free from fungus-growths.

To avoid disappointment the beginner is advised to wait until experience has been gained in experimental methods before attempting to work with culture solutions.

Some general results are therefore given here.

For full development, all the elements present in the list are necessary. A seedling grown without nitrogen will be very small; one without iron will not be of a normal colour; and, in general, the absence of any element will cause the seedling to suffer in some way. But, given all the elements present in the list, the seedling will thrive as well in the culture solution as in the soil, always provided that its roots will adapt themselves to the watery medium in which they are growing. It will be noticed that no carbon was included in the culture solutions; it can thus be proved that the plant does not require any carbon from the soil, although, as seen before (page 2), it is often present there in the form of carbonates.

The Force that produces Root-absorption.—The next step is to determine what it is that causes the absorption of water by the root. It is not possible actually to see the process directly, but an experiment can be set up in which a similar phenomenon can be observed, and which will serve to make clear the force by which the absorption is brought about.

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EXPERIMENT 6

Aim.—To determine what takes place when a sugar solution and water are separated by a permeable membrane, such as pig's bladder or a piece of parchment.

Method.—A piece of pig's bladder or parchment is soaked in water, then tightly stretched over the mouth of a long-stemmed thistle-funnel and tied on with thin string. The stem of the thistle-funnel is then held obliquely while golden syrup or a strong sugar solution

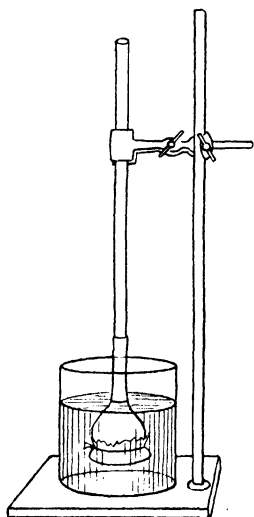


FIG. 4

is poured into the funnel until the bulb is full. If syrup is used it must be warmed so that it can flow down the tube easily, but it must not be made hot enough to injure the bladder. Syrup is easier to use than a sugar solution, as the latter may crystallize out if it is too strong.

When the bulb is full the thistle-funnel is fixed in an erect position by means of a clamp and retort-stand, and the level of the syrup is marked with a strip of gummed paper. The bulb is then suspended in a beaker of water in such a way that the level of the water in the beaker is the same as that of the solution in the thistle-funnel (Fig. 4).

Observations.—The liquid in the tube begins to rise and continues so to rise for some considerable time. Finally a maximum height is reached; and then the level of the liquid in the tube gets gradually lower. Meanwhile the water in the basin gets sweet.

Inferences.—The sugar must, in some way, have attracted the water through the bladder, and this with so much force that the liquid was able to rise in the tube against the force of gravity.

It was observed also that the water in the basin became sweet, therefore some of the syrup from the bulb of the funnel must have passed out into the water. This interchange of liquids is termed Osmosis.

The above experiment illustrates very roughly the method of absorption in the root of a plant. The syrup is analogous to the cell-sap, the membrane represents the wall of a cell of the root, the beaker of water takes the place of the water in the soil. Further, the passage of some of the sugar solution out into the water is analogous to the outflow of acid proved in Experiment 5.

A further experiment will determine whether sugar exerts a similar attraction when acting through the tissues of a plant instead of through pig's bladder.

EXPERIMENT 7

Aim.—To find out whether sugar possesses the power of attracting water through the cells of a plant.

Method.—For this experiment three large potatoes are used. Young ones are the best to work with, and they should have sound skins. From the end of each a sufficiently large piece is cut to enable the potato to stand steadily. At the other end a pit is made. This is best done with a cork-borer. Each pit should have a diameter of about half an inch and a depth of one inch. A width of about half an inch at the cut end of the potatoes is carefully peeled, and they are then placed in separate glass crystallizing-dishes.

A little crystallized sugar is put into two of the pits, and a few drops of water, just enough to moisten the sugar, are added. The pit in the third potato is left empty. Water is poured into two of the glass dishes, those which hold respectively the potato with the empty pit and one of the potatoes with sugar in the boring. Thus the second potato which has had

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sugar put into the cavity stands in an empty dish (Fig. 5).

Observations.—In about an hour's time the pits which contained the sugar are found to be half full of liquid. The empty pit still remains empty. Later the pits containing sugar become full of liquid and begin to overflow while the empty pit gets gradually drier.

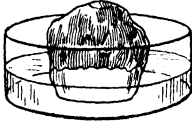


FIG. 5

No difference is at first discernible between the potato surrounded by water and that in the empty dish, but, after a day or so, the one not surrounded by water begins to look shrivelled, especially at the base, whilst the potato in the water remains as turgid as it was at the beginning of the experiment.

Inferences.—Osmosis has taken place between the sugar solution in the pit and the sap in the cells of the potato: the sugar has attracted the weaker sap from the cells of the potato adjacent to the pit, at the same time a little of the sugar has passed from the pit into these adjacent cells, thus strengthening their cell-sap; as a result of this increase in density, these cells have been able, in their turn, to draw sap from the next layer; this process has been repeated through each succeeding layer until the outermost cells of the potato have been reached. Thus a flow of liquid towards the pit has been set up.

In the case of the potato surrounded by water the outermost cells of the potato draw the water from the dish and thus a continuous flow is set up from the dish to the pit.

In Experiment 3 it was proved that absorption decreased as the strength of the solution absorbed increased, and that it ceased altogether after a certain strength of solution was reached. The reason for this is now clear. The solutions outside must be weaker than the cell-sap if these solutions are to be drawn into the root, and the greater the difference in the

densities of the cell-sap and of the solutions the more rapid will be the flow from the weaker to the stronger.

The Work of Root-hairs.—For the study of root-hairs, mustard or cress seeds may be germinated on damp flannel. An examination of the radicles of the seedlings shows them to be covered, at a little distance from the tip, by very fine hairs. These are the root-hairs and they last for a few days only. As the apex of the root grows, new root-hairs are constantly being formed just behind the tip, whilst those furthest from the tip die away as the new ones grow.

It is chiefly by means of the root-hairs that absorption takes place.

It is not, however, easy to demonstrate the absorptive power of the root-hair by any simple experiment, since the young root is able to absorb even when deprived of root-hairs. That this is so may be shown by cutting off the radicle of a broad-bean seedling at a point above the root-hairs. The seedling is not necessarily killed by this treatment, but immediately puts out secondary roots above the cut.

Moreover, when seedlings are grown with their radicles actually in water, root-hairs are usually not formed at all.

At the same time, under normal conditions of growth, it is through the very thin wall of the root-hair that osmosis takes place.

The Ascent of Water in Plants.—So far then it has been proved that a plant absorbs, by means of its roots, water from the soil and substances that are dissolved in the water. It has been seen that this solution passes up the stem and supplies the branches and leaves. Something of the nature of the force which causes the absorption of water and its passage through the plant has been learnt. Of this passage of the water there will be further discussion later, but it may be stated at once that the rise of water in tall stems is by no means fully understood. No adequate explanation

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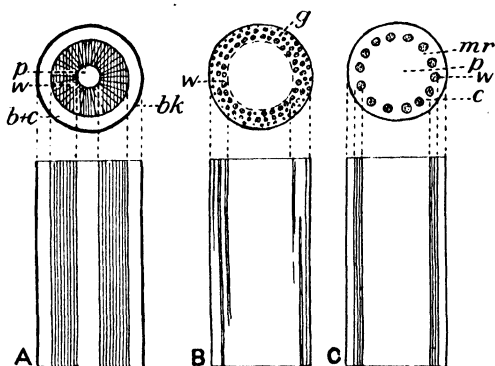
of this phenomenon has yet been advanced. The mighty force great enough to raise water to the top-most branches of the tallest trees, against the opposing force of gravity, is still a mystery.

By means of red ink or other coloured solutions it has been demonstrated that the water taken in by the root passes up through the stem and reaches the leaves. But although the leaves have become red the colour of the stem externally is unaltered. The ink cannot, therefore, have passed through the bark; it must have gone up through the inner part of the stem.

EXPERIMENT 8

Aim.—To find out where the water passes up the stem.

Method.—Three leafy twigs should be used, two being those of dicotyledons having respectively a



A, woody stem. }
 B, monocotyledonous stem. } Transverse and longitudinal
 C, herbaceous stem. } sections.

p, pith. *w*, wood. *b+c*, bast and cortex. *bk*, bark.
mr, medullary ray. *g*, ground tissue.

The distribution of the tissue which stains red is shown in each case.

FIG. 6

woody stem (e.g. beech, lime) and a herbaceous stem (e.g. sunflower, hogweed), and the third that of a

monocotyledon (*e.g.* Indian corn, palm). These should stand in some coloured liquid, such as red ink or a solution of eosin, until the leaves are turning red. At this point the stems should be cut transversely and longitudinally.

Observations.—The parts of the stem which become red are shown in the following table (Fig. 6):

	Woody Stem.	Herbaceous Stem.	Stem of Monocotyledon.
Transverse section.	A circular ring of tissue.	Small isolated patches arranged in a single ring.	Small isolated patches arranged irregularly.
Longitudinal section.	Two broad vertical bands.	Two narrow vertical bands.	Two or more narrow vertical bands on either side.
	Thus the red portion forms a hollow cylinder.	The red portion forms a ring of separate strands.	The red portion is in strands irregularly arranged.

When similar branches which have not been in red ink are examined, the same differentiation of parts can clearly be distinguished even in the uncoloured stem.

If the various parts are pricked with a needle, the red-staining portions will usually be found to be the hardest.

Inferences.—The red ink, or, more generally, the solution from the soil, passes up the stem through the hard part only. This part is the wood: it is arranged either in a complete cylinder or in isolated strands which may be regularly or irregularly disposed.

The Structure of the Stem of the Plant.—It will be

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well at this point to examine the stems rather more closely and to learn the names of the various parts noticed.

When looked at in transverse section the woody stem shows three concentric zones. The centre is made up of a white substance and is soft. This is the *pith*. The middle zone is not quite so white; it is harder; and faint radiating lines can be seen running through it. This part is the *wood*, through which the solution from the soil has been found to travel. The outermost layer is a very narrow one. If the stem is "peeled" the whole of this band comes off. The inner part of this is the *bast* and the *cortex*; the outermost part is the *bark*.

In the herbaceous stem the same parts are recognizable. In this case the wood and bast form isolated "bundles" arranged in a ring. It can easily be seen that there is a small part of each bundle lying towards the outside of the stem which does not stain when the twig is put into the coloured solution; this is the bast. Here too the pith and cortex are connected by strands of tissue; these are termed *medullary rays*.

In the monocotyledonous stem "bundles" are again present, but there is no differentiation between pith and cortex; for this reason all the tissue in which the bundles lie is termed *ground tissue*.

The Cause of the Ascent of Water in the Stem.—In Experiment 6 it was seen that the liquid in the thistle-funnel rose to a considerable height, but it did not continue to rise indefinitely, and the highest level reached was but a little way when compared with the height of a tall tree.

Now it has already been stated that no full explanation of the cause of the ascent of water through the stem has yet been given, but for that very reason it will be specially interesting to investigate it as far as possible.

If stem-sections are examined with a microscope, the wood, through which the water travels, is seen to

be made up of a number of little parts like elongated boxes in shape.

These are the "vessels" of the wood; they do not contain any cell-sap or any solution similar to the sugar solution experimented with in the thistle-funnel, or the acid cell-sap of the root-tip; that is, in the vessels of the wood, there is no osmotically active substance.

How then can the water pass upwards through the wood of the stem against the force of gravity, which must always be pulling it back again? The following questions naturally present themselves: Can it be pulled up from above, or forced up from below?

EXPERIMENT 9

Aim.—To find out if the leaves exert any pull which helps the water to rise in the stem.

Method.—For this experiment two leafy twigs are required. The twigs must be as nearly alike as possible so that fairly comparable results may be obtained. To this end it is well to cut them at the same time and from the same branch.

Two test-tubes are filled with water to the same level and the level in each case is carefully marked. A small quantity of some light oil such as cedar-wood oil is then poured over the water so that none of it may be lost by evaporation.

All the leaves are stripped from one of the branches, and the branches are then put into the test-tubes (Fig. 7).

Observations.—The water in the test-tube which contains the leafy branch diminishes at a much greater rate than that in the test-tube in which the leafless branch is standing.

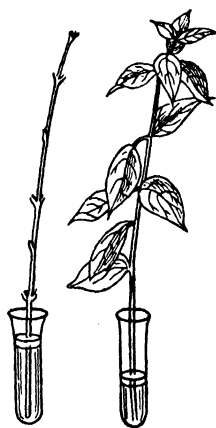


FIG. 7

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Inferences.—The presence of leaves on a twig is not altogether responsible for the passage of food solutions up a stem, but their presence greatly accelerates the rate at which the solution rises.

EXPERIMENT 10

Aim.—To find out if the root exerts any pressure which forces the water up the stem.

Method.—A small potted fuchsia plant is used for this experiment. The whole of the shoot is cut off at a distance of from one to two inches above the level of the soil. A long piece of narrow glass-tubing is then attached to the cut end and fixed uprightly by means of a clamp. Rubber-tubing is used to make the attachment, and is firmly fixed at both ends with wire or thin twine (Fig. 8). The plant is watered in the usual way.

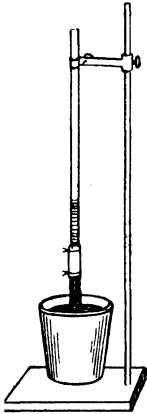


FIG. 8

This experiment should be set up several times at different seasons of the year.

Observations.—Water rises in the vertical glass-tube. The rate at which it rises is increased by warming the roots and decreased by cooling them. In spring and early summer the rise is rapid. It is slow in autumn, and often ceases entirely in the winter.

Inferences.—The root does exert a pressure which forces water upwards.

The push of the root, or "root-pressure," is regulated by the amount of water absorbed by the root, since the conditions that affect the rate of absorption (Experiment 3) similarly influence the rate of rise in the tube. Thus: *Root-pressure exists sometimes but cannot always be demonstrated.*

As seen in Experiment 10, root-pressure cannot

always be demonstrated. It can be observed only in certain plants at certain seasons of the year.

No trace of root-pressure can ever be detected on cutting the stem of a plant that has plenty of leaves and is growing in a dry, sunny atmosphere.

Of course this does not necessarily show that the force has ceased; it is merely negative evidence. At the same time it prevents our regarding root-pressure as an all-sufficient cause of the ascent of water through the stem.

Thus after making full allowance for the work done by the pressure from the roots and the pull from the leaves we are still left face to face with one of the big mysteries of plant-life.

Transpiration.—If the amount of water absorbed by a healthy growing plant be observed, and compared with the growth and increase in weight of the plant, it at once becomes evident that all the water absorbed cannot be retained. The method by which a plant gets rid of its surplus water must now be determined and some reason found for the absorption of so much more than seems to be necessary.

EXPERIMENT 11

Aim.—To determine how a plant gets rid of its surplus water.

Method.—A gas-jar is filled with water and fitted with a cork through which has been passed the stem of a leafy branch. The cork itself and all the connections are made airtight so that there may be no possibility of evaporation from the water in the jar. A second cylinder is then made perfectly dry. The ground glass edges of both cylinders are well vaselined and the dry one is inverted over the other (Fig 9).

Observation.—Very soon drops of water appear on the inner surface of the upper cylinder.



FIG. 9

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Inferences.—The water that has appeared in the upper cylinder must have been given off from the leafy branch in the form of vapour and then have condensed on the sides of the glass. Thus: *The leaves of a plant give off water-vapour.* This process is termed *transpiration.*

If the above experiment be kept under observation a little longer it is observed that the amount of water on the upper cylinder does not go on increasing.

This result seems at first a little contrary to expectation. It will be realised, however, by this time, that no experiment can give a false result; whatever the result, it must be true for the conditions set up.

The giving off of water from the leaves into the air is somewhat analogous to the drying of clothes on a clothes-line. The drier the air is the more quickly do the clothes give up the water contained in them. If this is also the case with the leaves it is seen at once that they have been put into an atmosphere which very soon becomes charged with the moisture that they themselves are giving off, and so the process under observation is checked and finally ceases entirely.

An experiment can now be set up to find out whether the rate at which water is given off by the plant really is affected by the dryness or dampness of the air surrounding it.

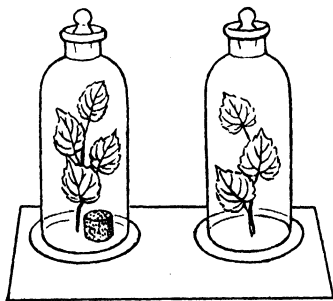


FIG. 10

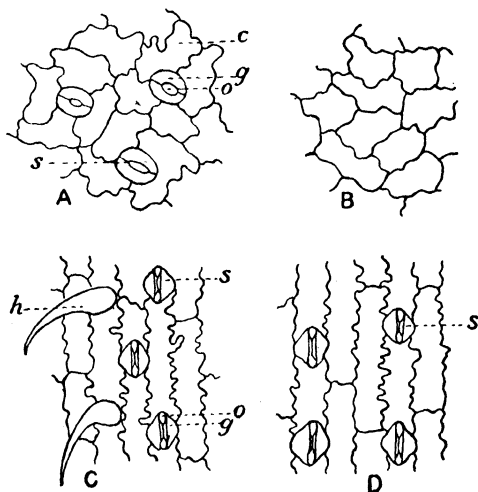
EXPERIMENT 12

Aim.—To find out whether the rate of transpiration is affected by the dampness or dryness of the surrounding air.

Method.—Calcium chloride must be used in this case. This substance has the power of absorbing moisture from the air around it.

In some plants, which grow in dry situations where little water is available, no transpiration at all is possible from the upper surface of the leaves. On the other hand when leaves present both surfaces equally to the sun, transpiration takes place equally from both sides.

When looked at with the naked eye a leaf appears to be covered by a complete skin, and it is difficult to see



A, privet leaf, lower surface. C, maize leaf, lower surface.
 B, " " upper surface. D, " " upper surface.
 c, cell. s, stoma. h, hair. g, guard-cell. o, opening.

FIG. 13

how transpiration can be effected at all. If, however, a piece of this "skin" is examined under a microscope it is seen to be made up of a number of tiny parts resembling somewhat the cells of a honeycomb (Fig. 13), and for this reason termed "cells" by the botanist. Scattered among the cells are little pores (s), and it is through these pores that the water-vapour escapes. They are called "stomata" or "mouths." Sometimes the stomata are to be found on both surfaces of the

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leaf as in the maize (Fig. 13); sometimes only on the lower surface as in the privet (Fig. 13); but always the amount of transpiration will be proportional to the number of mouths.

The stomata are bounded by two lips or "cells" called "guard-cells." These guard-cells have the power of opening and closing the pore, and so resemble the lips of our mouths. When they come together the stoma is closed and transpiration ceases; when they separate the stoma is open and transpiration takes place. In this way a plant is able to regulate the amount of water given off.

EXPERIMENT 16

Aim.—To find out whether the transpired liquid is pure water or whether any of the substances absorbed in solution by the root are lost at the same time.

Method.—Set up a leafy branch as in Experiment 11. Put some coloured substance (*e.g.* eosin) into the water in the lower jar.

Observation.—The water that collects on the upper jar is not coloured.

Inference.—The plant has retained the dissolved substance and the vapour transpired is pure water.

All the experiments that have now been worked have served to show the close link that exists between the giving off of water-vapour from the leaves and the absorption of solutions by the roots. The conditions that affect one affect the other similarly. If a plant is to grow and thrive, absorption must be somewhat in excess of transpiration. If transpiration exceeds absorption the plant withers. For this reason it is well to protect from the heat of the sun's rays transplanted seedlings whose young absorbing roots must have been injured during the removal.

The Value of Transpiration to the Plant.—Some

reason for the absorption of such an excess of water must now be looked for.

It has already been seen that roots can absorb dilute solutions only, that the rate of absorption is checked and finally stopped altogether by a gradual increase in the strength of the solution in which the plant is growing (Experiment 3).

The cause of this gradual decrease in absorbing power is obvious on referring back to Experiments 6 and 7, where it is seen that, if the solutions in the soil are of a higher density than the cell-sap, then the former cannot be osmotically attracted by the latter; that is, root-absorption cannot take place.

It therefore follows that the plant must take in an excess of water in order to get enough of the mineral foods which it obtains from the soil, as the mineral solutions are necessarily weak.

Other advantages are also derived by the plant from the transpiration current, as the rapid flow of water through the plant is termed. One important gain is the lowering of the temperature of the leaf during hot weather; such reduction of temperature being brought about by the evaporation of water from its surface.

Leaf-fall.—The connection between absorption and transpiration at once throws light on the question of the falling of leaves in autumn. The coming of winter means a decrease in the power of absorption by the roots, since it has been proved that absorption decreases as the cold increases. Transpiration decreases also, but, as has been seen, the power of a plant to prevent loss of water is only a limited one. The tree must therefore husband the water that it can obtain until warmer conditions bring back a renewed power of absorption. This it does by dropping its leaves, since it is through the leaves that the water would otherwise be lost.

Summary.—Something has now been learnt of the food that a plant gets from the soil.

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It has been found to consist of water in which are dissolved those mineral salts that are capable of solution in the water as well as those that can be dissolved by the acid of the root.

The method of absorption, the passage of the food solutions up the stem, and the transpiration of the surplus water have each been studied in turn.

We are now ready to turn to the second source of food for the plant, namely, the air.

CHAPTER II

I. THE COMPOSITION OF THE AIR

Before an attempt is made to solve any of the problems relating to absorption from the air it is necessary to know something of its composition. The air is gaseous and is without colour, taste, or smell. Whether it consists of one or of several gases must be determined. If there are several the special properties of each one must be investigated.

To find out whether two gases are alike or different may not seem at first a very easy matter. Gases cannot, as a rule, be seen, nor can they be handled, and therefore they are not capable of comparison by the methods applied in dealing with solids or with liquid bodies. They have nevertheless very characteristic properties, and each gas should be submitted to the following tests:

1. Its general appearance should be noted, its colour, and its smell, if any.
2. Its solubility in water must be determined. It is not always easy to determine the degree to which a gas is soluble. Various methods by which a rough estimate of the solubility can be obtained will be considered when dealing with individual gases.

3. By means of litmus-paper the acidity, alkalinity, or neutrality of the gas should be tested.

A strip of damp blue litmus-paper and one of red are put into a jar of the gas in question. If the gas is alkaline the red paper will be changed to blue; if acid, the blue will turn red; if neutral, the papers will remain unchanged.

4. A lighted splint should be passed into a jar of the gas to find out whether the gas burns or whether it is able to support combustion. Note the brightness of the combustion.

(This test might in some cases be a dangerous one to apply, but it is safe for all the gases dealt with in this book.)

5. The weight of the gas in comparison with the weight of air should then be tested.

This may be done by placing, mouth to mouth, two gas-jars, one containing air and the other the gas under investigation. Two sets of jars are arranged as in Fig. 14, in which A represents air and x the unknown gas. After a minute has passed the contents of all the jars should be tested. If x is lighter than A it will then be found in both the upper jars; if heavier, in both the lower ones.

6. Finally it must be determined whether or not lime-water is turned milky when the gas is passed into it.

If two unknown gases are compared and are found to respond in the same way to all these tests, they may then be regarded as one and the same gas; but if different results are obtained in any of these tests, then the gases must necessarily be different.

We are now in a position to return to the study of the nature and composition of air.

If a bell-jar is placed over a lighted candle, the candle very soon goes out. It seems, therefore, that the air must have been altered in some way by the

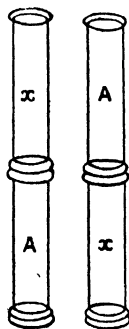


FIG. 14

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burning of the candle in it, since it is no longer able to support combustion.

Again, a fire will not burn without a "draught"; that is, a constant supply of fresh air must be allowed to pass through it.

Both these observations denote an intimate connection between the air and combustion; it is well, therefore, to begin investigations by burning something and then try to find out whether the air has been altered in any way by the combustion of the substance in it.

Phosphorus is commonly chosen for such investigation because it burns very readily. It is a yellow, waxy substance, and is poisonous. The smell of burning matches is due to the phosphorus contained in them.

Phosphorus should on no account be touched with the fingers, because the heat of the body is quite sufficient to cause it to ignite. Indeed it must always be kept under water, because it burns so readily and violently in air.

If a piece about the size of a pin's head is burnt in a porcelain dish the bright yellow flame and the dense white fumes may be noticed.

EXPERIMENT 17

Aim.—To find out any facts about the composition of air by burning phosphorus in it.

Method.—In order to test any change that takes place in the air due to the burning, it will be necessary to enclose a portion of air.

Float a little porcelain dish in a trough of water. Remove a stick of phosphorus from the bottle with a pair of forceps; put it between blotting-paper and cut off a piece about the size of a pea. Do not touch the phosphorus with the fingers; replace the stick immediately.

Then put the piece of phosphorus into the dish and cover with a stoppered bell-jar. While the bell-jar is being put into position the stopper must be taken out. You will readily see why this is necessary. Replace the

stopper. A certain amount of air has thus been enclosed in the bell-jar above the surface of the water (Fig. 15).

Again remove the stopper and ignite the phosphorus by means of a hot glass-rod or wire. Quickly replace the stopper.

Observations.—The phosphorus burns brightly, producing dense fumes. The level of the water inside the jar falls a little at first, then rises. When the burning is over, the water has risen about one-fifth of the height of the jar. The white fumes gradually dissolve in the water.

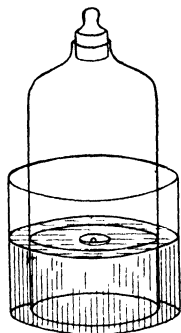


FIG. 15

As soon as the remaining gas is free from fumes, it is tested and the following observations made. (Several jars of gas will of course be necessary.)

1. It is invisible, colourless, and odourless.
2. If soluble in water, the solubility can only be slight, since the level of the water remains constant when the burning is over.
3. It is neutral to litmus-paper.
4. A lighted taper is extinguished and the gas itself does not burn.
5. It seems slightly lighter than air.
6. Lime-water is not turned milky by it. (Sometimes a slight milkiness is observed; this will be again referred to later.)

Inferences.—1. Air is altered both in character and quantity by the burning of a substance in it.

2. One-fifth of the air disappears; since this cannot have escaped, it must have united with the burning substance.

3. The gas that is left, which is four-fifths of the whole, is quite different in character. It can no longer support combustion.

4. Air must be made up of at least two gases, an active gas that unites with phosphorus producing a white

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powder that dissolves in water, and an inactive gas in which substances will not burn. The proportion of the active to the inactive is one to four.

It is not only by combustion that the active gas may be taken from the air. Some substances will absorb it without the application of any heat.

EXPERIMENT 18

Aim.—To find out whether damp iron filings will absorb the active gas from the air.

Method.—Some iron filings are tied up in a piece of muslin and put into a glass measuring-cylinder. (If a measuring-cylinder is not available a test-tube can be used instead.) The cylinder is then filled with water and inverted over a basin of water. The muslin with the filings will remain in position if made to fit fairly tightly.

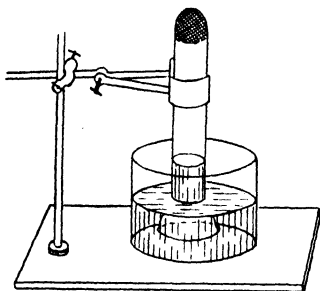


FIG. 16

basin. This can be done by means of a piece of bent glass-tubing (Fig. 16).

It may at first seem unnecessary to fill the cylinder with water and then blow the water out again, but there is no simpler way of getting the air inside at the same pressure as the air surrounding the cylinder. Try inverting an empty cylinder and note the result.

Observations.—Very soon the water inside the cylinder begins to rise, and continues to rise until one-fifth of the cylinder is filled with water; after this no further change takes place.

On testing the remaining gas it is found to be exactly

the same as the residual gas left after the burning of phosphorus in air.

Inference.—Damp iron filings take up the active gas from the air.

The name of the active gas in the air is *oxygen* and that of the inactive is *nitrogen*.

There are, in the air, other gases in small quantities, and these will be dealt with later. They were, of course, present in the residual gas left after the phosphorus had been burnt, since only the oxygen was taken from the air. It must therefore be remembered that the nitrogen tested was impure nitrogen, although the quantity of other gases contained in it was small. It is possible to prepare pure nitrogen, but it will not be very easy for us to do so at this stage. A pure specimen of the gas would give the same observations except in the case of the lime-water, which would not be turned milky at all, thus showing that the slight milkiness formed in the lime-water was due to some impurity and not to the nitrogen itself.

We have already tested the properties of nitrogen and found it to be an inert gas in which a taper will not burn. The properties of oxygen must next be tested. In order to do this a specimen of the gas must be prepared.

When phosphorus was burnt in air it united with the oxygen, forming a white powder called an oxide of phosphorus which rapidly dissolved in the water. It is extremely difficult to get the oxygen back again from the oxide of phosphorus, but many other substances containing oxygen give it up quite easily. Such a one is potassium chlorate. It is a white, crystalline substance, and is used in the making of fireworks and matches. When potassium chlorate is heated, oxygen is given off. It is given off even more readily and with less heat if a black substance named manganese-dioxide is mixed with it. The manganese-dioxide remains unchanged at the end of the reaction, but in some way it helps the potassium chlorate to decompose.

EXPERIMENT 19

Aim.—To prepare and collect oxygen and to test its properties.

Method.—Fit a hard round-bottomed flask with a cork and delivery-tube bent as in Fig. 17. Into

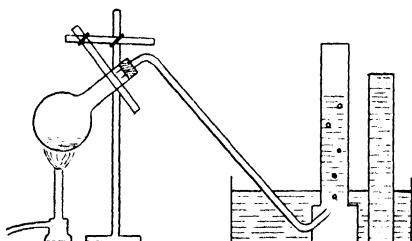


FIG. 17

the flask put about 20 grammes of a mixture of three parts of powdered potassium chlorate and one part of manganese-dioxide.

Clamp the flask so that the end of the delivery-tube fits through a bee-

hive shelf standing in a pneumatic trough of water. Gently heat the flask.

As soon as the heating has been carried on long enough to displace all the air in the flask, place an inverted gas-jar full of water over the beehive shelf and collect the gas that is coming off from the mixture in the flask. A round glass plate must be used for inverting the gas-jar.

When the gas-jar is full of the gas, cover it under water with a glass plate smeared with vaseline and remove it from the trough. Collect several jars in this way.

Before removing the flame disconnect the cork. This is very important. If it is not done the water will be drawn up the tube, as the gas in the flask contracts, and the flask will then probably crack.

Observations.—1. The gas is invisible. It has no colour or smell.

2. It cannot be very soluble in water, because the bubbles of the gas rose through the water and did not seem to get any smaller.

3. It is neutral to litmus.

4. A lighted taper is put into a jar. It burns much

more rapidly and brightly than it did in air. A glowing splint when put into a jar bursts into flame.

5. It is slightly heavier than air.

6. It does not turn lime-water milky.

Inferences.—Oxygen is an invisible, colourless and non-smelling gas. If soluble in water it must be only slightly so. It is neutral to litmus. Substances burn in it much more readily than they do in air.

Other substances in the air.—Thus it is seen that the air is made up almost entirely of oxygen and nitrogen. But there are also other gases present in small quantities.

The leaves of a plant are continually transpiring; it follows, therefore, that *the air must always contain a certain proportion of water-vapour*. It will now be shown that it also contains another gas which is most important in the life of a plant.

EXPERIMENT 20

Aim.—To find out the effect produced by air on lime-water.

Method.—Place some lime-water in a shallow dish and leave it exposed to the air.

Observation.—The lime-water gradually becomes milky.

Inference.—Since lime-water in an open dish becomes milky while that in a corked bottle remains clear, it seems probable that the change in the lime-water in the first case is brought about by contact with the surrounding air.

Now neither oxygen nor nitrogen can produce milkiness in lime-water. It is natural, therefore, to infer that there must be some other constituent in the air to which the milkiness is due. This constituent is the gas *carbon-dioxide*. The milkiness is caused by the combination of the carbon-dioxide with the lime of the

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lime-water to form a white powder named calcium-carbonate.

EXPERIMENT 21

Aim.—To find out whether the amount of carbon-dioxide in the air is affected by the breathing of living creatures in it.

Method.—Take two glass dishes each containing a little lime-water. Leave one on the table. Breathe vigorously into the other through a glass-tube.

Observations.—The lime-water in the second case very quickly turns milky, while the other becomes so only gradually.

Inference.—The amount of carbon-dioxide in the air is considerably increased by the breathing of living things.

EXPERIMENT 22

Aim.—To determine whether combustion affects the amount of carbon-dioxide in the air.

Method.—Two glass plates are taken. On one is placed a very short piece of lighted candle and on both a small dish of lime-water. Bell-jars are then placed over the plates.

Observation.—The lime-water under the bell-jar containing the lighted candle becomes milky much more quickly than the other.

Inference.—The amount of carbon-dioxide in the air is increased by the burning of substances.

(It must be noted here that it is only those substances that contain carbon which produce carbon-dioxide on burning.)

Carbon-dioxide is thus formed in the atmosphere by the breathing of all living things; it is also produced when certain substances burn; and it may be shown too that it is formed when animal and vegetable matter decay.

Some of this gas must now be prepared in order that its properties may be tested more fully.

EXPERIMENT 23

Aim.—To prepare and collect carbon-dioxide and to test its properties.

Method.—Put about 20 grammes of limestone, or marble broken into small pieces, into a flat-bottomed flask, fitted with a thistle-funnel and delivery-tube.

A two-necked bottle is convenient, but an ordinary flask fitted with a two-holed rubber-stopper answers quite well. A rubber-stopper is better than a cork, as it is difficult to get the latter air-tight.

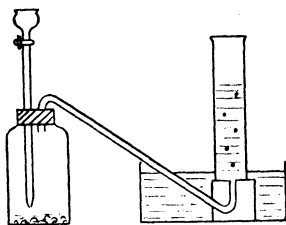


FIG. 18

The delivery-tube should be bent as shown in Fig. 18 or Fig. 19.

Cover the marble with water and add a little concentrated hydrochloric acid through the funnel. The funnel need not necessarily have a tap, but, if there is no tap, care must be taken that the stem of the funnel reaches the liquid in the flask, otherwise the gas evolved will escape through the funnel.

The gas is readily given off without the application of heat. It may be collected either over water as oxygen was collected (Fig. 18), or by downward displacement of air (Fig. 19).

Observations.—1. The gas is colourless and invisible. It has a faint, pungent smell.

2. The bubbles appear to get rather smaller as they rise through the water, thus suggesting that the gas is somewhat soluble.

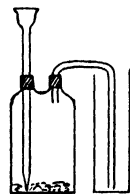


FIG. 19

The solubility may be further tested in the following way: A jar of the gas is opened under water; the plate is replaced so that a small quantity of water is enclosed; the jar is well shaken and again opened under water. The water then rises very gradually in

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the jar, therefore some of the gas must have been dissolved in the water.

3. If a little moist blue litmus-paper is put into the gas, or, better still, into the solution of the gas in water, the litmus-paper slowly turns red.

4. If a lighted taper is put into the gas it is immediately extinguished.

To show well the extinguishing power of carbon-dioxide ignite some turpentine in a saucer, then invert a bell-jar filled with the gas over the flames.

5. The gas can be collected by downward displacement of air. It is therefore heavier than air.

6. If a little lime-water is poured into one of the jars, or if the gas be allowed to bubble from the end of the delivery-tube into some lime-water, the lime-water becomes milky.

Inferences.—Carbon-dioxide is an invisible, faintly smelling gas. Its solubility in water is greater than that of oxygen. It is slightly acid. It will neither burn itself nor allow other substances to burn in it. It is heavier than air and turns lime-water milky.

Summary.—The knowledge that has now been gained respecting the composition of the air may be summarised as follows:

It is a mixture of gases.

About four-fifths of the whole is the inert gas nitrogen.

About one-fifth is oxygen, a gas in which substances very readily burn.

Carbon-dioxide, a heavy gas in which substances will not burn, is present in varying but small amount.

(The quantity differs according to the locality. In country air there are from 3 to 4 parts in 10,000, but in towns the proportion is greater.)

In addition water-vapour is present.

The air also contains other rare gases and various impurities, but for the purposes of this book these need not be taken into account as they are present in such small quantities.

The relation that exists between a plant and the surrounding air can now be dealt with. Answers to the following questions will be sought.

Does a plant get any food from the air? If it does, what is the nature of the food taken, and under what conditions is it obtained?

II. THE ABSORPTION OF FOOD FROM THE AIR

Experiments dealing with the absorption of food from the air are more difficult than those connected with absorption from the soil, because invisible gases are here being dealt with.

A few preliminary experiments will be made.

EXPERIMENT 24

Aim.—To find out whether air can pass from the atmosphere into and through a leaf.

Method.—A piece of straight glass-tubing drawn out to a point at the lower end and a piece of glass-tubing bent at right angles are put through a two-holed cork. The cork is then fitted into a conical flask or a bottle partly filled with water.

In the upper end of the straight tube a stout leaf is fixed; a laurel leaf is a suitable one for the purpose.

A piece of rubber-tubing with a clip is attached to the end of the right-angled tube.

The junction between the leaf and the tube and all the joints in connection with the cork are then made airtight (Fig. 20).

If a big succulent leaf such as a *funkia* can be obtained the apparatus may be set up more simply. In this case the straight glass-tube can

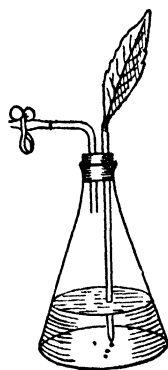


FIG. 20

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be dispensed with and the leaf stalk inserted through the cork (Fig. 21).

The amount of air in the bottle is now reduced by drawing it out by suction through the right-angled tube, and then the end is closed by means of the clip.

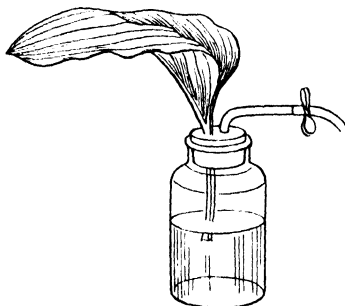


FIG. 21

Observations. — Bubbles appear in the water, in one case at the end of the drawn-out tube, and at the end of the petiole in the other. The bubbles continue to come off for a considerable time.

Inferences.—Since the evolution of the bubbles continues for some time the air thus given off cannot all have been inside the leaf at the start. The bubbles must therefore be air which has come into the flask from the atmosphere to take the place of that which has been drawn out. This air must have passed through the leaf, since no other route exists.

Therefore it is possible for the air to pass into the tissues of a plant.

EXPERIMENT 25

Aim.—To find out whether air passes into a leaf equally through both the upper and under surfaces.

Method.—Apparatus similar to that set up for the last experiment is required. Two leaves of the same kind are used. One of these is smeared with vaseline on the upper surface, and the other on the lower.

Observations.—Air is easily drawn through the leaf which is vaselined on the upper surface, but it is extremely difficult, and, in some cases, impossible, to get any bubbles from the leaf which has been vaselined on the lower surface.

Inferences.—Air is taken into the leaf chiefly, and, in some cases, entirely, through the lower surface.

The observations made in the above experiment recall the results obtained in the experiments on transpiration (page 28), when it was found that transpiration takes place most actively from the lower surface of the leaf. In this case, as in that of transpiration, the number of stomata is the determining factor.

The use of the stomata is thus twofold : they provide a means whereby the water-vapour can pass out of the leaf, and, further, it is through the stomata that the air enters.

The two foregoing experiments have shown that it is possible to draw air through a leaf. The presence of air in the leaf under natural conditions will now be demonstrated.

EXPERIMENT 26

Aim.—To show the presence of air in a leaf.

Method.—Some water is boiled until it is free from air. A leaf is then put into the water and gently heated. If air is present in the leaf it will expand on heating ; as a result there will not be room for it all in the leaf and some must escape into the water.

Observations.—Bubbles of air come out into the water. They are specially noticeable from the lower surface of the leaf.

Inferences.—*Air is present in a leaf*, and, when forced out, it escapes chiefly from the lower surface.

By these preliminary experiments it has thus been shown that air is actually present in the tissues of a plant, and, further, that air can be drawn into the plant from the surrounding atmosphere.

Starch Formation in the Plant.—The main question can now be dealt with : it must be determined whether the plant really *feeds* on the air ; that is, whether it uses any part of the air to build up its own plant-tissues.

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This is not easy. The question must be attacked in an indirect manner, and the process of reasoning must be carefully followed, otherwise the value of the experimental evidence may be lost.

A simple substance commonly found in plant-tissues is selected; and, by experiment, the conditions under which this substance is formed in the plant are determined.

Now, one of the simple substances most commonly found in the tissues of a plant is *starch*. Potatoes and wheat contain a great deal of starch; and, as it will be shown presently, starch is not confined to those parts of a plant that we use as food.

Starch is therefore chosen for the investigation, and the conditions under which it is formed are investigated. It is necessary to have some simple test by the application of which the presence of starch can always be recognized.

EXPERIMENT 27

Aim.—To show the effect produced by iodine on starch.

Method.—Take a small quantity of starch, powder it and mix it into a paste with a little water. Then add to it a few drops of very weak solution of iodine in potassium iodide.

Next take several substances which are known to contain starch, and others that are known to be without it. Suitable substances containing starch are, for instance, a bean seed, a slice of potato, and a starched collar; as examples of substances without starch, a piece of white chalk or of washing soda may be used. Each of these substances should be treated in turn with the iodine solution.

Observations.—The starch is turned a purple blue colour by the iodine solution, so also are all the substances which contain starch. Those without it, on the other hand, just take on the brown colour of the iodine solution.

Inference.—*Starch is turned blue by iodine solution.*

This is the method that is always employed to detect the presence of starch. This knowledge can now be applied to the case of a green leaf.

EXPERIMENT 28

Aim.—To test for starch in a green leaf that has been picked in the afternoon of a sunny day.

Method.—The working out of this experiment is complicated by the fact that the leaf is green. This green colouring matter, or chlorophyll, must therefore first be got rid of, otherwise it will mask the blue iodine reaction. A liquid must be used which will dissolve out the chlorophyll from the tissues of the leaf, but which will leave the starch unaltered.

It is evident from common observation that chlorophyll is not soluble in water; vegetables that have actually been boiled in water still retain their green colour. Chlorophyll is, however, soluble in methylated spirit.

Chlorophyll dissolves out slowly in cold methylated spirit, but it comes out much more quickly on heating. This must be done very carefully, as methylated spirit ignites so readily.

It is well to boil the leaf in water first. As it boils, bubbles of air are seen to escape from the leaf, especially from the under surface. By this preliminary boiling the air in the leaf is expelled and its place taken up by water. When the escape of bubbles has almost ceased the leaf should be taken from the water and boiled in methylated spirit. The green colouring matter is then readily dissolved, as the passage of the spirit into the leaf is rendered easy.

When the leaf is quite colourless it should be washed in water and a little dilute solution of iodine then poured over it. After a few minutes it should be again washed in water.

Observations.—The leaf becomes a dark blue colour.

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Inference.—Starch is present in a green leaf that has been picked in the afternoon of a sunny day.

Now it will be remembered that the aim stated on page 46 was to investigate the conditions under which starch can be formed in the plant, and to ascertain, if possible, the part taken by the air in its formation.

EXPERIMENT 29

Aim.—To find out if light and darkness influence the formation of starch in the leaf.

Method.—Over both sides of a leaf of a growing plant pin carefully pieces of silver paper. The paper should be turned over at the edges and fastened so that the pins do not injure the leaf. Cover another leaf with two pieces of paper, each of which has a hole cut in the centre. The two holes must be alike in size and shape, and the papers must be placed over the leaf-surfaces so that the holes accurately coincide.

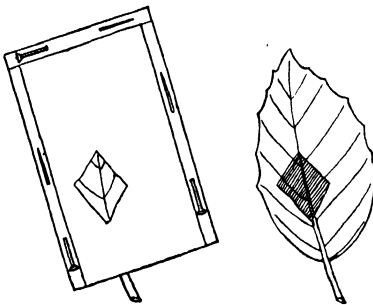


FIG. 22

In this way one leaf is completely in the dark; the other is darkened except for the central portion. The leaves should be left for two days, or longer if the weather is not sunny; then they should be picked in the afternoon and tested for starch.

Observations.—No starch is present in the leaf that was wholly covered.

Starch is present in the uncovered part of the second leaf (Fig. 22).

Inference.—*Starch is formed only under the influence of light; it cannot be formed in darkness.*

It is thus proved that light is necessary for the formation of starch in leaves. A further experiment may be made to amplify and confirm the above, or may be substituted for it if preferred.

EXPERIMENT 30

Aim.—To find out if light and darkness affect the formation of starch in the leaf.

Method.—Choose a potted plant that has a large number of leaves. Take off one leaf; boil it in water; then put it into a bottle of methylated spirit. Carefully label the bottle with the date. Put the plant into the dark. The next day take off another leaf and treat this in the same way as the first. Similarly, each day for a week remove one leaf. Then bring the plant into the sunlight again and, in the light, continue the collection of leaves for a second week.

At the end of the fortnight examine all the leaves for the presence of starch.

Observations.—The first leaf gave a dark blue starch reaction. In the second the reaction was fainter. After that the amount of starch gradually decreased until there was none remaining.

On the eighth day, that is, the first after the plant had been taken from the dark, a little starch was again found. Each day after this the amount of starch increased.

Inferences.—*A green leaf loses its starch if kept in the dark and regains it when brought back again into the light.*

EXPERIMENT 31

Aim.—To find out which light-rays are most effective in starch formation.

Method.—The light-rays are made to pass through coloured screens (blue or red) before they reach the plant. The screens may be of red or blue glass, or coloured solutions may be used.

If the screens are to be of glass, two wooden boxes,

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large enough, when standing on end, to contain potted plants, are covered with dull black paper both inside and out: or, better still, the inside only may be papered, while the outside is painted black. Margarine boxes are a convenient size.

The covers of the boxes are replaced, one by a sheet of blue glass, the other by a sheet of red.

This is a useful piece of apparatus, and it is therefore worth while to cover the boxes carefully. To keep the sheets of glass in position a beading may be put round the edges of the boxes and the glass fitted into this with

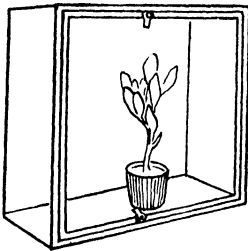


FIG. 23

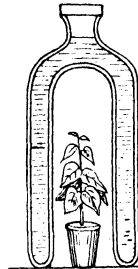


FIG. 24

small brass catches, or, if preferred, the glass may be put into frames and fitted to the boxes with hinges and a latch.

A plant depleted of starch is then put into each box, and the boxes are placed so that a good light falls on the coloured screens (Fig. 23).

For carrying out the experiment by means of coloured solutions, special double bell-jars are prepared (Fig. 24). By means of these double bell-jars the working of the experiment is rendered very simple. The coloured solution is put into the outer jacket of the jar, and underneath the jar is placed a plant whose leaves have been depleted of starch. The whole apparatus is then placed in a good light.

The blue solution is made by adding ammonia to a solution of copper sulphate. At first a precipitate is

formed, but, on the addition of more ammonia, the precipitate is dissolved and a blue solution is formed.

The red solution is prepared by dissolving potassium bichromate in water. A saturated solution should be made. This substance is extremely poisonous.

The double-jacketed bell-jars are very convenient for this experiment, but they are not essential and they are expensive.

To carry out the experiment without the double bell-jar it is well to use a water plant. *Elodea canadensis*, the American pond-weed, serves the purpose well.

Some pieces of *Elodea* are depleted of starch by being kept in the dark in the usual way. They are then placed in two bottles of water in which is small shot acting as ballast. The bottles are corked and the joints thoroughly waxed. The coloured solutions are put into two large glass jam or pickle jars, and the small bottles containing the *Elodea* lowered into the solutions (Fig. 25). As before, the whole apparatus must be put into a good light.

Observations.—When the usual starch test is applied it will be found that in each case a great deal of starch has been formed by the plant in the red light, but very little by the plant which has been subjected to the blue rays.

Inference.—The red rays of light are more effective than the blue in starch formation.

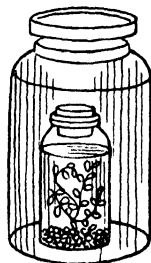


FIG. 25

EXPERIMENT 32

Aim.—To find out whether the formation of starch is influenced by temperature.

Method.—*Elodea*, the American pond-weed, or some other water-weed, is used for this experiment, as the temperature of water can be kept more uniform than that of air.

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Put two vessels, each containing a piece of *Elodea*, into the dark, until the plants are depleted of starch.

Then surround one of the vessels with ice, put a thermometer into each, and place both in a good light.

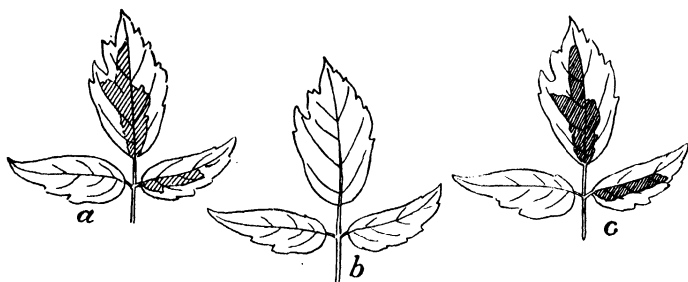
Observations.—No starch is formed in the plant contained in the vessel that is surrounded with ice, but it is formed in large quantities in the control experiment.

Inference.—Warmth is necessary for the formation of starch.

EXPERIMENT 33

Aim.—To find out if the colour of the leaf affects the formation of starch in it.

Method.—Choose a plant whose leaves are green in



a. The variegated leaf that was tested. The green part is shaded.

b. The leaf after it had been boiled in methylated spirit.

c. The leaf after treatment with iodine. The part which turned blue is shaded.

FIG. 26

part only. Variegated maple gives very good results, but any variegated leaf can be used.

In all experiments that depend on the iodine test it is advisable to select thin leaves, as it is difficult to see the colour reaction through a very thick skin.

From the results obtained in Experiments 29 and 30, it is clear that the afternoon is the best time for the working of this experiment, as then the leaf has had sufficient time to make a good supply of starch.

Pick a leaf. Make a careful drawing of it, showing accurately the position of the green and the white portions. Then test for starch in the usual way.

Observation.—Only that part of the leaf which was originally green is turned blue by the iodine (Fig. 26).

Inference.—*Starch is formed in the green part of the leaf only.*

EXPERIMENT 34

Aim.—To determine whether the absorption of air by a leaf is essential to the formation of starch in it.

Method.—The leaves of a *calceolaria* or other small potted plant are depleted of starch in the usual way.

Three of the leaves are then smeared with vaseline; one on the upper surface, one on the lower, and the third on both surfaces.

The plant is put again into the light, and, when a sufficient time has elapsed, the leaves are tested for starch.

It will be necessary in this case to get rid of the vaseline before applying the iodine test. To this end the leaves may be put into xylol or petrol until the vaseline is dissolved.

Observations.—Starch has been formed plentifully in the leaf whose upper surface is vaselined. Very little is found in the leaf that had vaseline on the lower surface. In the leaf smeared with vaseline on both surfaces no starch reaction is obtained.

Inference.—No starch is formed if the absorption of air is prevented.

Three conclusions have now been drawn relating to the formation of starch in the leaf:

1. It cannot be formed in the dark.
2. It cannot be formed in the absence of chlorophyll.
3. It is formed in green leaves exposed to light under ordinary atmospheric conditions.

Now starch is made up of the three elements carbon,

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hydrogen, and oxygen. Hydrogen and oxygen, together, form water, which is taken in from the soil by the roots of the plant. But it has already been shown, by the use of culture-solutions, that the plant is not dependent on the soil for its carbonaceous food (page 13). It follows, therefore, that a plant must obtain carbon in some form from the air.

The air, it will be remembered, is made up of oxygen, nitrogen, carbon-dioxide, and water-vapour, together with various rare gases and impurities in minute quantities. The only possible source of carbon is, therefore, the carbon-dioxide (a compound made up of carbon and oxygen) which is present in the air.

The importance of the element carbon is very great. It is essential to all living bodies.

It is not easy to determine practically by any direct method whether the plant absorbs the carbon-dioxide of the air. The reason for this will be understood when the section on the breathing of the plant has been studied. An indirect method will therefore be adopted, and an experiment will be carried out to ascertain if starch continues to be formed in an atmosphere that is deprived of carbon-dioxide.

There are three substances that have the power of absorbing carbon-dioxide. These are:

1. Lime-water.
2. Caustic potash solution.
3. Soda-lime.

In any particular case the substance that is most suitable must be selected. For instance, if the aim is to show that carbon-dioxide is being absorbed, then lime-water should be used because the absorption of carbon-dioxide is quickly demonstrated by the milky reaction given. When, however, the aim is the complete absorption of all carbon-dioxide present, then a strong solution of caustic potash is more suitable. Again, soda-lime can be used when a solid substance is required.

Inferences.—Grape-sugar can be recognized by the red-brown precipitate formed when a solution of it is boiled with a few drops of copper sulphate solution and excess of potash; in the case of cane-sugar the same precipitate is formed in the solution, but not until it has been boiled with an acid.

These reactions may cause a little difficulty at first, but the tests must be satisfactorily applied before proceeding further. In order to give more practice several plant-storage organs should be tested for sugar.

EXPERIMENT 38

Aim.—To test for sugar in the carrot, onion, beetroot, turnip.

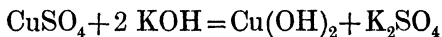
Method.—Extracts of the vegetables are made and each is tested as in Experiment 37.

Observations.—Grape-sugar is present in the carrot, onion, and turnip.

Cane-sugar is present in the beetroot.

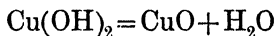
The chemical changes that underlie these reactions will easily be understood by those who have some knowledge of the subject.

Copper sulphate and potash react, giving a flocculent precipitate of copper-hydroxide:

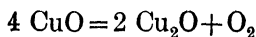


The copper-hydroxide precipitate is then dissolved again by the addition of excess of potash.

Copper-hydroxide is made up of cupric-oxide and water. Thus:



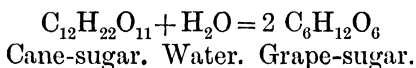
Now certain sugars have the power of taking oxygen from other substances and “reducing” them to less oxidised forms. The equation



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shows how cupric-oxide may be reduced to cuprous-oxide, which is a red-brown precipitate.

The previous experiment has shown that grape-sugar is a reducing sugar. Cane-sugar is not a reducing sugar, but is converted into one when it is boiled with a trace of mineral acid. The change which takes place is termed hydrolysis and consists in the addition of a molecule of water to the molecule of the non-reducing sugar, by which it is changed or "inverted" into a reducing sugar. Thus:



EXPERIMENT 39

Aim.—To determine whether the starch formed in the leaf is converted into sugar.

Method.—A few leaves are picked in the afternoon of a warm, sunny day. They are then put on damp blotting-paper in a well-corked bottle and placed in the dark for about three days.

When the leaves are picked they contain a large quantity of starch. It has already been shown that starch does not remain in the leaves if the plant is kept in the dark. In this case, however, the removal of any substance from the leaf is prevented by its separation from the plant.

At the end of three days the following tests are made:

1. Some of the leaves are tested for starch.
2. Some of the leaves are tested for sugar.
3. Some leaves freshly gathered from the plant are tested for sugar.

Observations.—No starch is found in the leaves although they have been separated from the plant.

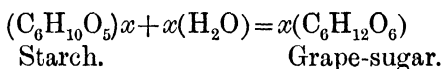
Those, however, that were submitted to the second test were found to contain sugar.

No sugar reaction is obtained in the case of the freshly gathered leaves.

Inferences.—The starch formed in the leaf is converted into sugar, a soluble substance; and in this form it travels about the plant.

The change by which starch is converted into sugar is one of hydrolysis (page 60), similar to that by which cane-sugar is converted into grape-sugar.

It may be represented as a chemical equation. Thus :



The exact value of x is not known.

It has already been shown that, when cane-sugar is boiled with a mineral acid, it is converted into grape-sugar.

In the following experiment it will be shown that the process whereby starch is converted into sugar is similar to that by which grape-sugar is formed from cane-sugar.

EXPERIMENT 40

Aim.—To find out what happens to starch when it is boiled with a mineral acid.

Method.—Small pieces of potato, or powdered starch, can be used in this experiment. To this, water and a few drops of hydrochloric acid are added. The whole is then boiled. At intervals of two or three minutes a little of the liquid is removed and treated with iodine in order to test for starch.

When the iodine solution no longer gives any starch reaction the remaining liquid is tested for sugar.

Observations.—Each time the iodine test is applied the amount of starch is found to decrease. Finally no starch is left. The remaining liquid shows the presence of a reducing sugar.

Inference.—Starch is converted into sugar when boiled with a mineral acid.

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It has thus been proved: firstly, that the starch formed in the leaf is converted into sugar; and, secondly, that it is possible to convert starch into sugar by boiling it with a mineral acid.

Now it is quite evident that the starch present in the leaf is not naturally hydrolysed by a mineral acid in this way. The hydrolysing agent in the case of the leaf is a ferment termed "diastase." This diastase can be extracted from the leaf, but the operation is beyond the scope of this book.

The action of diastase differs from that of a mineral acid in that it is able to effect the change at the ordinary temperature.

The soluble sugar into which insoluble starch has now been converted travels down the stem, and some of it is afterwards reconverted into starch, in which form it is stored as a reserve-food in tubers and bulbs and other such structures.

Eventually the starch and sugar formed in the plant, together with the substances taken up in solution from the soil, are used by the plant for the building up of its solid framework and for the formation of the living substance, the protoplasm, contained within it.

EXPERIMENT 41

Aim.—To determine where the food material, manufactured in the leaf, passes through the stem.

Method.—A ring of tissue about an inch wide and reaching as far as the wood, is removed from the stem of a branch of a tree or from the main stem of a young potted seedling-tree. A two-year-old sycamore answers well.

The removal of this ring of tissue, consisting of bast, cortex, and bark (page 18), does not interfere with the passage of the watery solutions up the stem, since they ascend through the wood only (Experiment 8).

Observations.—The following observations were made

in an experiment in which two young sycamore trees were used. The figures 29 (a) and 29 (b) are photo-

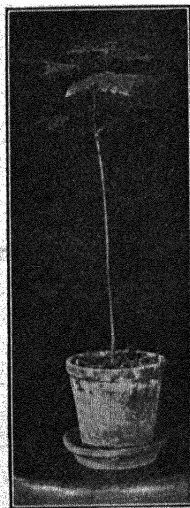


FIG. 29 (a)

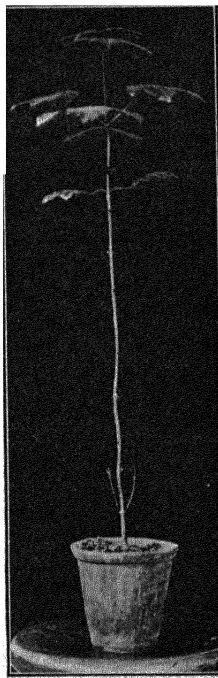


FIG. 29 (b)

graphs of the two plants taken on May 14th before the ring of tissue was removed.

The stems were then ringed a few inches above the earth.

The ringing of the stem made no difference to the unfolding of the new leaves. A circular swelling formed round the stem immediately above the ringed portion. In the case of *b*, dormant buds below the ring began to develop. The plants were

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again photographed on June 20th (Figs. 30 (*a*) and 30 (*b*)).

After this the petioles of the leaves began to droop. This was especially the case in plant *a*, where, by the



FIG. 30 (*a*)

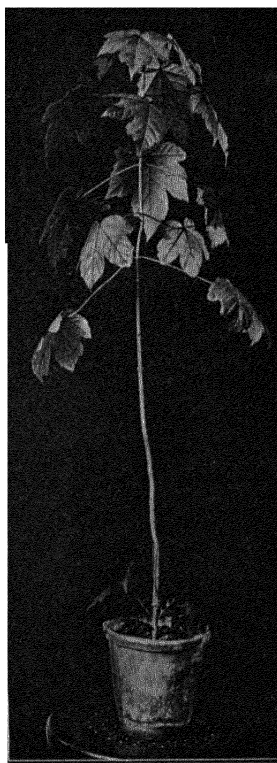


FIG. 30 (*b*)

end of the month, the leaf petioles were hanging vertically and the leaves were curled up.

The plant *b* did not suffer so much. The new shoots, developed from the dormant buds below the ring,

continued to grow and thrive. The swelling above the ring increased, and tissue-formation took place, almost covering the original wound. Figs. 31 (*a*) and 31 (*b*) are

FIG. 31 (*a*)FIG. 31 (*b*)

photographs of the plants taken on July 1st. Fig. 32 shows the lower part of plant *b* taken on the same day.

From this date plant *a* withered away. There was no attempt at new bud formation in the axils of the leaves. The leaves did not fall off.

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Plant *b* fared better. The lower shoots thrive in a normal manner. The leaves of the main shoot drooped more and more until they also hung vertically. They did not fall off, but good winter resting buds were formed in their axils and also a large terminal bud.

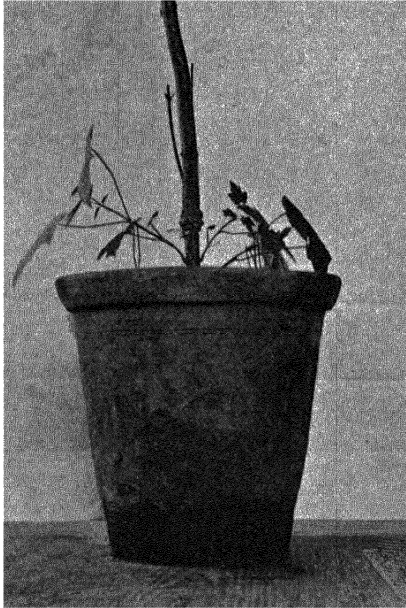


FIG. 32

Inference.—Putting all these facts together the following conclusions are drawn :

1. The ringing of the stem does not at first cause any apparent check to the growth of the plant.
2. Later the growth is checked, and in the case of *a* the whole plant died.
3. The difference in the behaviour of the two plants must be due to the development of the dormant buds below the ring in the case of *b*

4. The only consistent explanation of these facts is that the food-material, elaborated in the leaves, passes through the plant in the tissue outside the wood. Assuming this, the facts recorded can be explained thus:

In plant *a* the leaves continue to unfold after "ringing," as the water supply has not been checked; the expanded leaves then manufacture starch; the starch is converted into sugar; it is then further combined with the substances from the watery solutions coming from the soil. The final product of this assimilation then passes down the stem until it is stopped by the cut ring. As a result no further manufactured food-stuff ever reaches the root; the root is unable to perform its functions properly and to grow with the growth of the shoot above; the plant ultimately dies as a result of the starvation of the root.

In plant *b* the initial stages are similar to those of plant *a*, but later the root is kept from starving because nourishment is sent to it by the new leaves that grow *below* the ring. The root-development, which thus takes place, is not sufficient to maintain proper development of the main shoot above the ring; as a result of this the leaves of the main shoot cannot form their cork-layers and so they droop, but do not fall off; but the root-development is sufficient to keep the plant alive for a considerable time and to enable the shoot to form its winter resting buds.

Since this explanation fits all the observed facts, it may be concluded that *the food-material manufactured in the leaves passes to different parts of the plant through the tissues outside the wood.*

Comparison of the Feeding-process in Animals and Plants.—The feeding-process in plants and animals can now be compared.

Animals are unable to utilise, as food, the constituents of the air and the soil. They cannot build up starch from carbon-dioxide and water. They must, therefore, feed on the starch and sugars that the plants have already manufactured.

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Thus it is seen that plants only can live independently on this planet. Without them the simple constituents of air and water could not be used for food and animal life could not be sustained.

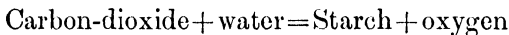
The important conclusion is now reached that *all animal life, our own included, depends for its very existence on the activity of the green plant.*

It is now possible to consider more fully the cause of this dependence of the animal world upon plant-life.

Carbon-dioxide and water cannot of themselves form starch. Whenever it is required to build up any substance from two simpler substances some form of *energy* must be supplied. Familiar instances of this occur in the experiments made in the chemical laboratory, where energy, in the form of heat, is constantly being applied to bring about chemical combination.

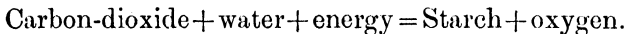
So it is in the case of starch formation.

To write the equation



is not to state the case correctly.

The right equation is:



What then is this energy? and why cannot animals make starch in a similar way?

The answer to these questions is that *the ultimate source of all this world's energy is the sun, and only chlorophyll is able to absorb this energy for the building up of food.*

Health Value of keeping Plants Indoors.—There is one interesting and very important point which may be referred to here.

It will be remembered from the lime-water test (Experiment 21) that in breathing, or respiration, a large proportion of carbon-dioxide is given out.

Further, we know from experience that a room gets "stuffy" when several people are in it.

The conclusion is therefore drawn that the "stiffness" is due to excess of carbon-dioxide in the air, and that the reduction in the amount of carbon-dioxide will render the atmosphere healthier. Here then is the health reason for having green plants in the house.

It must not, however, be forgotten that this advantage holds only during daylight, since no absorption of carbon-dioxide can take place by the plant in the dark.

(*Note.*—It has recently been suggested that the unhealthy atmosphere produced in a room containing several people is due to increase in amount of moisture rather than to that of carbon-dioxide; and, further, that the "stiffness" is lessened when the air is kept in motion.)

SECTION II

THE BREATHING OF THE PLANT

IN the breathing process of animals a larger proportion of carbon-dioxide is given back to the air than is taken from it. This was proved in Experiment 21, where it was seen that the amount of atmospheric carbon-dioxide is being continually increased as a result of the breathing of animals.

Now plants, like animals, are living things. They feed. They have the capacity for growth. Do they also breathe?

The first step towards finding an answer to this question is to determine whether or no plants give out carbon-dioxide.

Just at first this may look like a contradiction of what has been already learnt. But it is not necessarily so.

It has been seen that, given certain conditions, a plant takes in carbon-dioxide from the air in its feeding process (page 56). But this absorption of carbon-dioxide for food does not, in any way, hinder the plant from giving off the same kind of gas in the absolutely distinct process of breathing.

In trying to find out, however, whether there is evolution of carbon-dioxide, great care must be used to prevent the plant from taking back, as food-material, the carbon-dioxide that it may have given out by breathing. If the reabsorption of the carbon-dioxide is not prevented, the lime-water test will, of course, fail.

Obviously, then, the plant must not be allowed to obtain food from the air while breathing experiments

cient to extend for at least ten inches on each side of the V-shaped bend. The apparatus is now made air-tight.

The level at which the liquid stands in the two arms of the tube is marked with gummed paper and the thermometer read. The temperature may then be kept constant by means of a wet cloth.

Now since no substance is put into the flask to absorb the carbon-dioxide, it follows that there will be no change in the level of the coloured liquid if the amount of oxygen inspired equals the amount of carbon-dioxide expired, provided always that there are no other factors which nullify the conclusions arrived at. If, however, the volume of oxygen taken in exceeds that of carbon-dioxide given out, the column of coloured liquid in the tube will move towards the flask; conversely, the column of liquid will move in the direction away from the flask should the volume of carbon-dioxide expired exceed that of oxygen inspired.

Observations.—For a time the level of the liquid remains practically stationary. Soon, however, the liquid is slowly pushed down the arm of the tube which is adjacent to the flask. (It is not generally possible to get the column of liquid further than the bend of the tube, as the gas from the flask manages to escape when the end of the column of liquid stands at the bend.)

Inference.—It may be roughly estimated from this experiment that the amount of oxygen inspired is normally equal to that of carbon-dioxide expired, but that, in the apparatus set up, the normal result is soon falsified by the conditions of the experiment itself.

(*Note.*—When seeds are germinated in a confined space so that the supply of external oxygen is limited, the seedlings are able to utilise the oxygen contained within themselves for their respiration. This utilisation of the oxygen contained within the tissues of the plant, for respiratory purposes, is termed *Intramolecular Respiration*. ~~When intramolecular respiration is taking~~

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place carbon-dioxide continues to be evolved, thus there ceases to be any relation between the amount of oxygen taken in and that of carbon-dioxide given out.

The change in the level of the liquid which was observed in the above experiment, after the apparatus had been set up for some time, was largely due to the fact that intramolecular respiration had begun. Another factor which caused movement of the column of liquid was the evaporation of water-vapour from the surface of the peas and paper.)

EXPERIMENT 46

Aim.—To determine the amount of carbon-dioxide that is given out in the process of respiration.

Method.—From Experiment 45 it is seen that, within very rough limits, the amount of carbon-dioxide expired is equal to the amount of oxygen inspired.

Assuming, then, that these amounts are equal, the quantity of oxygen measured in Experiment 44 may be taken also as a measure of the amount of carbon-dioxide expired.

EXPERIMENT 47

Aim.—To find out whether a plant breathes in the dark as well as in the light.

Method.—The foregoing experiments can be worked again, the apparatus being kept in the dark.

Observations.—Similar observations will be obtained.

Inference.—*Plants breathe always, night and day.*

EXPERIMENT 48

Aim.—To find out whether a plant can live if it is deprived of oxygen.

Method.—In this experiment some substance must be used that has the power of absorbing oxygen from the air. Pyrogallic acid answers this purpose. In

order to demonstrate its absorptive power a small quantity of the acid, dissolved in water, may be put into a well-corked bottle and left for a few hours; then, by the extinction of a lighted taper which is thrust into the bottle, the absence of oxygen is proved.

Two healthy bean-seedlings are suspended, by means of cotton, in two bottles; at the bottom of one bottle is a solution of pyrogallic acid; in the other an equal volume of water. The seedlings must not touch the liquids. The bottles are then well corked (Fig. 37).

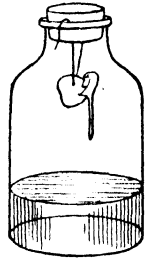


FIG. 37

Observations.—The seedling which is suspended over the water continues to grow, while the one placed in the bottle containing pyrogallic acid very soon dies.

Inference.—*A plant cannot live if deprived of oxygen.* In other words, a plant dies if it is unable to breathe.

(*Note.*—In the case of the seedling that was suspended over pyrogallic acid, a little further growth is observed before the seedling begins to wither. This is due to the fact that the oxygen contained within the seedling itself is being used up in its respiration (page 75).

EXPERIMENT 49

Aim.—To find out whether the breathing of plants affects the temperature of the surrounding air.

Method.—A glass funnel is filled with peas that have been soaked for two days and are just beginning to germinate. The funnel is then supported in a tumbler at the bottom of which is a little water. A bell-jar is placed over the whole. The bell-jar is fitted with a one-holed cork, and a thermometer is passed through the hole so that its bulb dips down into the peas (Fig. 38).

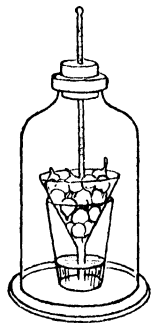


FIG. 38

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A control experiment is set up in which the peas are replaced by cotton-wool or sawdust.

Observations.—On reading the thermometer it is found that the temperature of the germinating peas is higher than that of the control experiment.

Inference.—The breathing of plants causes the temperature of the surrounding air to rise.

Health Value of Plants Indoors.—It has now been proved that plants, like ourselves, continually take in oxygen and give out carbon-dioxide. This may at first sight seem to contradict what was said on page 68 as to the health value of plants in the house.

It is evident that the breathing of the plant helps to make the air "stuffy," just as our own breathing does. But during the day the green plant takes in carbon-dioxide as food and gives out oxygen and thus helps to purify the air; the amount of carbon-dioxide absorbed as food far exceeds that expired in the breathing process. Thus a purifying of the air is effected by the presence of the plant. But this advantage lasts only during the day. As the evening approaches the feeding process slackens and finally stops, but the breathing never ceases, and so, during the night, plants, like ourselves, only vitiate the air, and should therefore be removed from the rooms in which we sleep.

The Significance of the Breathing Process.—The true meaning that underlies the need for continuous breathing in all living things can now be explained.

Something of the process has been learnt. It has been found that all living things, plants as well as animals, breathe constantly as long as they continue to live (Experiment 47); and, further, that death follows when breathing ceases (Experiment 48). So far as the interchange of gases is concerned, breathing consists in the taking in of oxygen and the giving out of carbon-dioxide; but this is no explanation of the fact that breathing is essential to life.

As long as a plant or an animal lives, it is constantly

expending, in its growth and in its varied activities, the energy which it possesses within itself; and, unless this energy can be restored, it must die.

As a result of the absorption of food, new plant—or animal—tissues are constantly being built up, and these tissues form a storage of energy in a potential form.

The meaning of the word “potential” in this connection will be readily understood from an illustration. Water, stored in a reservoir, has “potential” energy. It can be used to drive an engine or to turn a mill-wheel. But, before it can be of any use whatever, it must be released from the reservoir and allowed to expend its energy in movement to a lower level, *i.e.* the “potential” energy must be converted into “kinetic” energy, or, in other words, the energy of power must be changed into the energy of movement.

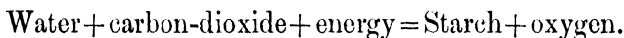
Similarly, plant substances which are formed during assimilation must be broken down in order that the energy which is stored up in them may be liberated. The oxygen that is taken in in respiration acts as the destroying agent. It enters into combination with chemical compounds, formed in the plant, and breaks them down; as a result of this, energy is liberated. Some of this energy is dissipated in the form of heat, as was shown by the rise in the temperature of the air surrounding germinating peas (Experiment 49), but the greater part of the liberated energy is available for use in the further growth and activities of the plant.

It is thus seen that breathing is a destructive process by means of which energy is liberated. For this reason it is continuous, taking place in darkness as well as in the light.

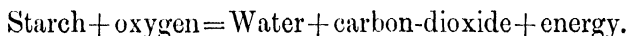
Exactly opposite is the process of assimilation. Here, from the carbon-dioxide taken in from the air and the water absorbed from the soil, a plant manufactures substances such as starch. This is a building-up process, and, for this reason, energy must be supplied. It follows, therefore, that it can take place only in the daytime, in the light of the sun, the earth's one source of energy.

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The equation that represents the building up of starch was given on page 68:



The following equation may now be compared with the above:



This equation represents the destructive action of oxygen on starch.

The first equation shows the assimilation or building-up process for which energy must be supplied. The second equation is that of respiration or breaking-down in which energy is liberated.

Summary.—The main facts that have been learnt concerning the relation between the plant and the surrounding air may now be tabulated.

Air is used by the plant in connection with the processes of feeding (carbon-assimilation) and breathing (respiration).

Carbon-assimilation.

Carbon-dioxide is taken in.
Oxygen is given out.

The air is purified.

Only green parts of plants can use carbon-dioxide for food.

Energy is required, therefore carbon-assimilation takes place only in sunlight.

Respiration.

Oxygen is taken in.
Carbon-dioxide is given out.

The air is rendered impure.

Every part of the plant breathes.

Energy is set free, therefore respiration takes place always, in darkness as well as in the light.

SECTION III

THE GROWTH OF THE PLANT

Introductory.—When a seed is put into the ground and given suitable conditions it begins to germinate. First the root emerges and penetrates into the soil, after this the shoot grows up into the air. In time, a large branching system of roots is developed in the soil, and, above the ground, a stem with many branches bearing leaves, flowers, and finally fruits.

It is not easy to say exactly what is meant by growth. It is not simply increase in size and bulk. A sponge, when placed in water, swells and increases in weight, but it has not grown, and, when taken out of the water, it shrinks to its original size. Growth necessarily implies a *permanent* change in form and can only take place in living things.

It has already been seen that two processes are continually going on in the plant, one building up the tissues and the other breaking them down. Growth takes place when the process of building up is greater than that of breaking down.

In order to study the elementary conditions and phenomena of growth a large number of seedlings at various stages are required.

Useful seedlings for the purpose are those of the broad-bean, French-bean, giant-sunflower, and Indian corn. These are all large seedlings and can be grown satisfactorily indoors.

The Germination of the Seed and the Growth of the Seedling.—The morphology of the growing seedling is well and fully described in most elementary text-books of botany. This section will therefore be con-

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finer to simple experiments dealing with causes and methods of growth, and the experiments should be worked in conjunction with the morphological study of the germination of the seed.

For this reason it is sufficient here to trace briefly the course of events in some individual case, say in the germination of a broad-bean.

When a broad-bean seed is planted in a pot of earth, and kept damp and in a warm place, it very soon begins to grow. First it absorbs some of the moisture and consequently swells. This swelling produces so much pressure on the coat, or testa, that a rupture is caused. The testa bursts at its weakest point, that is, at the point where there was already a small hole, the micropyle. The first root, or radicle, whose tip was just beneath the hole, protrudes through the ruptured coat and grows down into the soil. Soon after this, the first shoot, the plumule, bent like a hook and with its yellow leaves all crowded together at the tip, pushes its way through the soil up to the light and the air.

The seed germinates because it has been supplied with all the conditions necessary for its development.

These conditions, which together make up its environment, may be examined separately in order to find out which are essential to the growth of the seedling.

A. Water as a Necessary Factor in Germination

EXPERIMENT 50

Aim.—To find out whether a seed will germinate without water.

Method.—Some bean seeds are planted in a pot of well-dried soil, and others in a pot of damp soil. The seeds in the damp soil are watered regularly in the usual way.

Observations.—The seeds in the damp soil germinate. Those in the dry soil do not.

Inference.—A seed will not germinate without water.

That a seedling is able to absorb water has already been proved in Experiment 1.

Now soak a broad-bean in water for a day. Remove it and squeeze gently. Water oozes through the micropyle. Is it then through the micropyle that the water was absorbed?

EXPERIMENT 51

Aim.—To determine whether water is absorbed by the broad-bean seed through the micropyle only, or whether it can be taken in through the testa as well.

Method.—Suspend a broad-bean in a beaker of water by means of cotton so that the micropyle is well out of the water (Fig. 39).

Observations.—The immersed portion of the bean becomes swollen first. Later the swelling extends to the part of the bean that is out of the water.

Inferences.—The broad-bean absorbs water through the testa as well as through the micropyle. The water that has been absorbed can pass from one part of the seed to another.

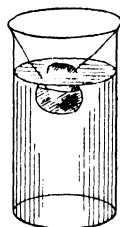


FIG. 39

The absorption of water by a seed is termed *Imbibition*.

B. Food as a Necessary Factor in Germination

The question of the food of the adult plant has already been dealt with in a long series of experiments. From these experiments it has been learnt that the plant gets food both from the soil and from the air. It remains now to find out whether these sources of food-supply are available and necessary for the early stages in the life of the plant.

It will be remembered that the food from the air is taken in only by the green parts of plants. It follows, therefore, that the seedling cannot take in food from

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the air during the early stages of its growth, since this source of supply is not available until some green leaves have unfolded.

On the other hand, the substances dissolved in the water, which constitute the food-supply from the soil, are available to the plant from the beginning of its growth. Whether or no these dissolved substances are necessary for germination can be shown by the following experiment.

EXPERIMENT 52

Aim.—To find out whether a seed requires food from the soil in order to begin to grow.

Method.—Three broad-beans are planted. One is put into earth, one into cocoanut fibre, and the third is suspended over water in a corked bottle so that it is in a damp atmosphere. The bean that was planted in cocoanut fibre is watered with distilled water.

Thus one only of the three seeds is provided with mineral food.

Observations.—All three seeds begin to grow.

Inference.—Food from the soil is not necessary in the initial stages of growth.

It has thus been proved that a seed can germinate without nourishment either from air or soil. This does not imply that growth is possible without food, although it may appear at first sight as if it were a case of a "building-up" without a "breaking-down." But such a case is impossible. The growth of the seedling necessarily involves an expenditure of energy; and this energy must be constantly renewed or the seedling will die. Somewhere "potential" energy must be converted into "kinetic" energy. Or, in other words, assimilated food substances must be broken down so that energy necessary for the growth of the seedling can be liberated.

Where then does the seedling obtain this assimilated food, since it cannot manufacture any for itself?

In answer to this question it may be said that the

food need not necessarily come from without. An examination of any seed always reveals a supply of food-stuff either in the embryo itself, or packed around it. In the seeds suggested as types, the broad-bean, French-bean, and sunflower store food-material in the cotyledons of the embryo; in the case of the maize the food-material is stored in the endosperm which surrounds the embryo.

An experiment can now be made to find out whether the growing seedling uses the food that has been stored up in the seed.

EXPERIMENT 53

Aim.—To find out whether a growing seedling uses the food that is stored up in the seed.

Method.—Three French-beans are planted. One (*a*) is allowed to grow naturally. In the case of the second seedling (*b*) the cotyledons are cut through at the base as soon as they are sufficiently above the surface of the earth to admit of the cut being made without injury to any other part of the seedling. When the cuts have been made and the cotyledons thus disconnected from the rest of the plant, it is better not to attempt to remove them, as such removal would probably cause injury to the shoot or root of the young plant. The cotyledons are cut off from the third seedling (*c*) as soon as the first foliage leaves have expanded.

Observations.—The results noted are, that

(*a*) grows and develops;

(*b*) quickly withers;

(*c*) is not affected by the removal of the cotyledons.

Fig. 40 is a photograph of two French-bean seedlings growing under similar conditions in one pot. From one of the seedlings the cotyledons were removed as soon as that operation was possible without injury to the rest of the seedlings. Up to that time the seedlings were equally healthy.

Inference.—The seedling uses the food stored in the seed until the unfolding of the green leaves enables it to build up food substances for itself.

EXPERIMENT 54

Aim.—To determine the nature of the food that is stored in the cotyledons of the French bean.

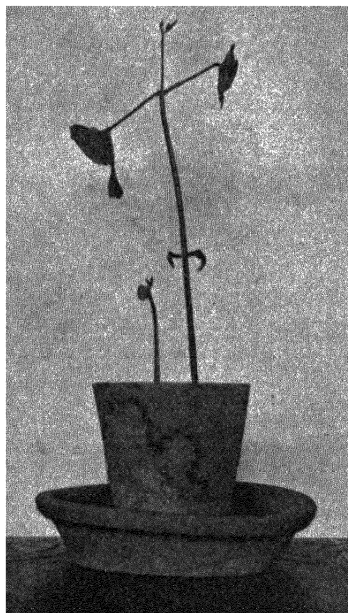


FIG. 40

Method.—Break a cotyledon across and place the cut end in iodine solution.

Observation.—The broken end of the cotyledon turns blue.

Inference.—Starch is stored in the cotyledons of the French-bean.

The food-store in all seeds is not in the form of starch. Oils and fats are sometimes stored in seeds; and, in other cases, the store consists of proteins, substances which resemble the white of egg.

C. Air as a Necessary Factor in Germination

In the course of the experiments described in this book, it has been seen that a plant takes in two constituents of the air, namely, oxygen in the process of breathing, and carbon-dioxide as a food.

Of these two gases, the carbon-dioxide is of no use to the germinating seed, since it contains no chlorophyll by means of which the carbon-dioxide can be assimilated; this, however, is compensated for by the store of food within the seed itself.

On the other hand, it has been proved that germinating seeds do take in oxygen (Experiment 43); and, further, that a seedling dies if the air which surrounds it is deprived of oxygen (Experiment 48).

It is thus seen that *a germinating seed does not require carbon-dioxide from the air, but it dies if deprived of oxygen.*

D. Light as a Necessary Factor in Germination

EXPERIMENT 55

Aim.—To find out whether light is necessary to the growth of a seedling.

Method.—Seeds of various kinds are planted in pots. Some of the pots are then kept in a dark room or large airy cupboard, the remainder are allowed to grow under the normal condition of alternating light and darkness. Temperature and other factors must be, as nearly as possible, the same for both sets of pots.

Observations.—The seedlings kept in the dark grow, but the growth is abnormal. The stems become long, thin, and are without strength, while the leaves remain small and yellow. Fig. 41 is a photograph of two broad-bean seedlings, one of which has been grown in the light and the other in darkness, all other conditions having been the same for both seedlings.

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Plants grown in the dark never reach maturity, but wither away after a time.

Inferences.—A seed germinates quite well in the dark, and the seedling continues to grow as long as the food that the parent plant has stored up for it in the seed lasts; but eventually it must have light in order that

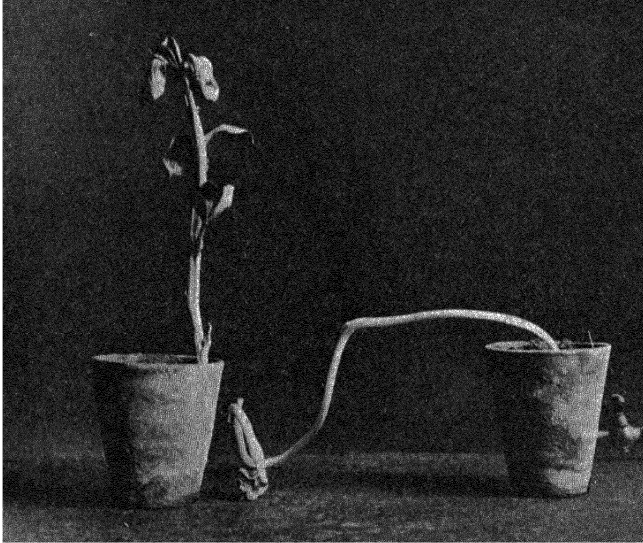


FIG. 41

the leaves may expand, become green, and perform their work as feeding organs. The plant which is kept in the dark grows excessively long in its vain attempt, seemingly, to reach the light, and dies at last for lack of food.

E. Life as a Necessary Factor in Germination

If a seed is boiled for some time in water it is no longer able to germinate. Thus there is a vital differ-

ence between the boiled and the unboiled seed: one can germinate, the other cannot; or, differently expressed, one is living, the other is dead.

F. Heat as a Necessary Factor in Germination

Heat and cold are relative and not absolute terms. The seeds in our gardens do not germinate in the spring until a certain degree of temperature is reached; further, seeds of any kind kept in a warm greenhouse germinate earlier than those of the same kind sown in the open.

Accurate experimental work on this point is beyond the scope of this book. It can only be stated that some degree of warmth is necessary for germination and that the degree differs for different seeds.

Plants that require a large amount of heat must grow in tropical countries; in colder countries are to be found only those plants that can thrive at lower temperatures.

In this country the limits of temperature between which plants grow are a few degrees above freezing-point and about 50° C., but the plant's greatest activity occurs between the temperature 25° C. and 30° C.

The conditions under which a seed can germinate have now been investigated. If these conditions are fulfilled seedlings will grow healthily and the method of their growth can then be studied.

Direction of Growth.—The first observations to be made are on the direction of growth of the various parts of the seedling. It is noticed that the root makes its way down into the soil, while the shoot grows up into the air. Further investigations will determine the causes which bring about this directive growth.

EXPERIMENT 56

Aim.—To show the direction of growth taken by the root and by the shoot of seedlings when the seeds are planted in various positions.

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Method.—(a) A gas-jar is fitted with a cork. A small groove is cut in the lower end of the cork, and into this is fixed one end of a strip of sheet cork measuring about one inch by six.

Three soaked broad-beans are then pinned on to the piece of cork. The beans are arranged so that the radicle points, in one case, downwards; in the second, upwards; and, in the third case, horizontally. The pins can be stuck through the cotyledons, but care must be taken to prevent their penetrating plumule or radicle.

A little water is put into the bottom of the jar, but

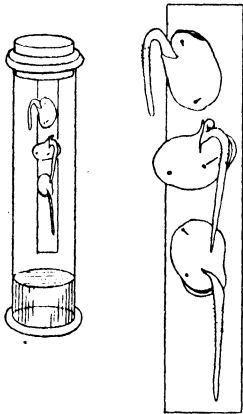


FIG. 42



FIG. 43

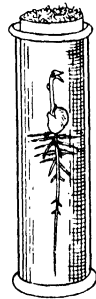


FIG. 44

the strip of cork should not dip into it. The jar is then covered with black paper. This is a very simple way of showing the direction of growth taken by the root, but the following method is preferable for demonstrating the direction of growth of the shoot, as it does not necessitate the use of a closed jar.

(b) A gas-jar or lamp-chimney is lined with a roll of blotting-paper. The roll is filled up with moist sawdust or moss so that the blotting-paper may be kept damp. Seeds are then carefully placed between the glass and the paper in the three positions given above.

Observations.—1. When the seed is planted so that the radicle points downwards, the radicle grows vertically downwards and the plumule vertically upwards (Figs. 42 and 43).

2. If the radicle of the seed is made to point upwards when planted, the radicle grows upwards for a little way, it then bends right over and grows downwards; the plumule curves and grows upwards (Figs. 42 and 44).

3. When the radicle of the seed points horizontally it grows horizontally for a little way; it then bends at right angles and grows downwards; the plumule grows upwards (Fig. 42).

Inferences.—The plumule always ultimately grows straight upwards and the radicle straight downwards whatever the position in which the seed is planted.

(*Note.*—Method (*b*) of the above experiment is one that will constantly be found useful when early stages of growth are under investigation.)

EXPERIMENT 57

Aim.—To find out whether light affects the direction of growth taken by the shoot.

Method.—A wooden box—a margarine box is suitable for the purpose—is painted black on the outside and lined with black paper. A small hole is made in the cover of the box near one end. The box then stands on one of its shorter sides and a small pot containing a sunflower seedling is put inside.

It will be necessary to remove the cover at intervals in order to water the developing seedling, but care must be taken not to alter the position of the pot.

If the cover does not fit exactly, black paper should be pasted round the edges of it.

The box must then be placed in a good light.

The seedling is now illuminated from one point only.

(See also the method used in Experiment 59.)

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Observations.—After a while the tip of the shoot grows through the hole.

If the method given for Experiment 59 be used, it will be seen clearly that the stem of the shoot places itself in the same direction as that in which the light is falling, while the leaves arrange themselves at right angles to the source of light.

Inference.—*A shoot grows towards the light, the positions taken by the stem and leaves respectively being such as to secure for the leaves the maximum amount of light.*

The way in which the shoot reacts in response to the stimulus exerted by the direction of the rays of light is termed *Heliotropism*. The shoot grows towards the source of light, placing itself in the same line as the rays of light. It is described therefore as being *positively heliotropic*.

EXPERIMENT 58

Aim.—To find out whether light affects the direction of growth of the root.

Method.—Get a wooden box—a margarine box answers the purpose well, or a chalk box may be used. Take off one of the long sides and fix a piece of glass in place of the cover. Let the box stand on the remaining long side and fill it with earth.

Place a row of broad-beans close to the glass. (See also the method used in Experiment 59.)

Observations.—The roots do not grow vertically downwards but disappear from the side of the glass into the darkness of the soil.

Inference.—*A root grows away from the light.*

The direction of growth taken by the root is therefore said to be *negatively heliotropic*.

EXPERIMENT 59

Aim.—To find out which rays of light have the greatest influence in determining the direction taken by the different parts of the plant.

Method.—The three boxes prepared for Experiments 31 and 57 can be used again in this investigation. The two, which are respectively fitted with sheets of red

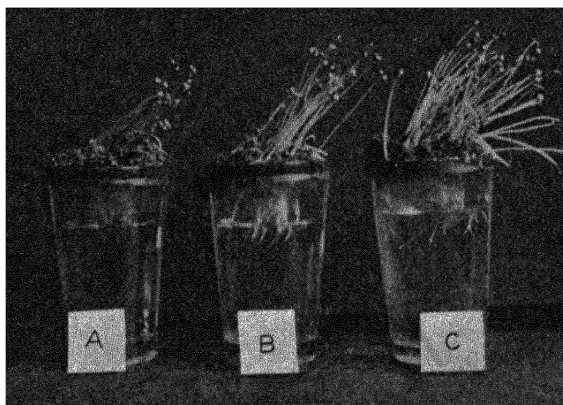


FIG. 45

and blue glass, are ready for use. In the third box the cover must be replaced by a sheet of plain glass.

Three tumblers are almost filled with water. A piece of coarse net is put over the top of each and kept in place by a rubber band. Damp sawdust or fibre is placed over the net, and on this mustard seeds are sprinkled.

One of these tumblers is then put into each box and the boxes are placed in a good light.

Observations.—In every case the shoots of the seedlings grow towards the light and the roots away

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from the light, the angle of inclination being greater for the shoot than for the root. The seedlings growing in white light are most affected (Fig. 45, A). For those growing in blue light the directive influence is rather less (Fig. 45, B). The seedlings upon which the red light falls are only slightly inclined from the vertical (Fig. 45, c).

Inferences.—The blue rays have the greatest influence in determining the direction taken by the different parts of the plants; very little influence is exerted by the red rays.

EXPERIMENT 60

Aim.—To find out whether moisture affects the direction of growth of the root.

Method.—Two small sieves or gravy strainers are suitable for this experiment. These must be filled with

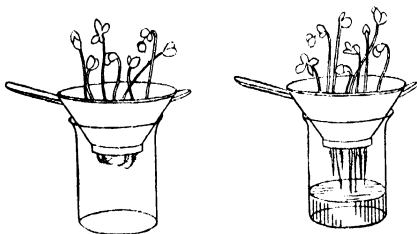


FIG. 46

damp sawdust and planted with mustard seeds. The meshes must be large enough for the roots to pass through. The sieves are placed over two tumblers or beakers, one of which contains water, while the other is left empty. The sawdust must be kept damp.

Observations.—The roots of the growing seedlings come through the holes of the sieves and begin to grow downwards.

In the case of the seedlings growing over water the downward growth of the roots is maintained. In the other case, however, the root-tips soon turn upwards and creep along the damp surface of the sieve (Fig. 46).

Inference.—Roots grow towards moisture. The attraction that water possesses for the root is sufficient to overcome its natural tendency to downward growth.

The response produced by the presence of moisture on the direction of growth of the root is termed *Hydro-tropism*. Roots are said to be *positively hydrotropic*.

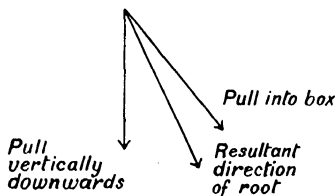
The glass-fronted box made for Experiment 58 can be used to show very prettily the direction of growth taken by each part of a seedling.

EXPERIMENT 61

Aim.—To show clearly the direction of growth taken by all the parts of a seedling bean.

Method.—Three or four broad-bean seeds are planted in the glass-fronted box used in Experiment 58. The beans are arranged so that the radicle in each case is close to the glass and points downwards.

Three directive forces, as has already been seen, act on the root of the developing seedling. One of these forces pulls the root vertically downwards; the other two draw it away from the glass towards darkness and the moisture of the soil. As a result the root grows obliquely in a direction which is the resultant of the three forces that act upon it. This is shown graphically in the figure.



It is thus seen that the roots can be made to grow close to the glass by tilting the box forward so that the plane in which the glass lies is that of the resultant direction taken by the root.

It is advisable to cover the glass with a piece of black paper. Thus, by reducing the amount of light

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that would otherwise reach the roots, the box need not be tilted at so great an angle.

Observations.—The primary root grows straight down to the base of the box. The secondary roots

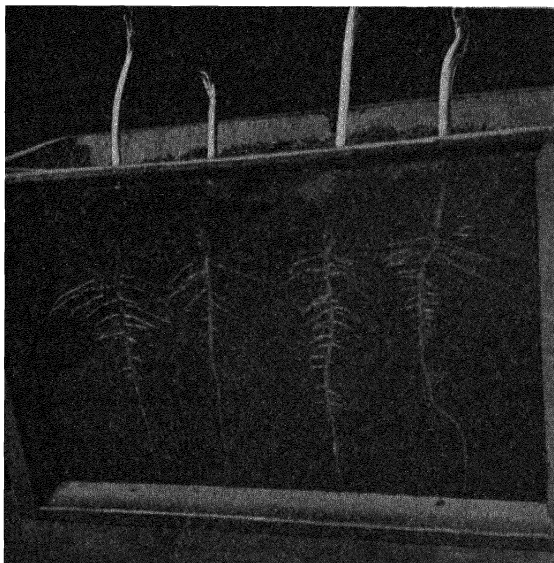


FIG. 47

grow out almost at right angles to the primary root, while the shoot grows vertically upwards (Fig. 47).

By the foregoing experiments it has been proved that the main root of a plant always turns downwards when allowed to grow naturally in damp soil. The cause of this downward growth must now be investigated.

When a body is dropped it falls at once to the ground. This is a direct result of a force by which everything is attracted to the centre of the earth. This force is termed the Force of Gravity, and the

earth's centre, to which everything is attracted, is termed the Earth's Centre of Gravity.

Experiments must now be carried out to determine whether this force of gravity is responsible also for the downward growth of roots. To this end the effect produced on the direction of growth of the root, when the force of gravity is rendered inoperative, must be studied.

A careful examination of Fig. 48 will show clearly how the force of gravity may be rendered of no effect. The same bean-seedling is shown in eight positions which are arranged symmetrically round a central point. The positions

form a series of pairs in which the action of gravity on the root-tip is equal and opposite for the two members of any pair; for instance, the effect of the action of gravity when in position (b) would be neutralised by the effect produced when in position (f), and similarly for the other pairs. Generally, the root in all the positions shown

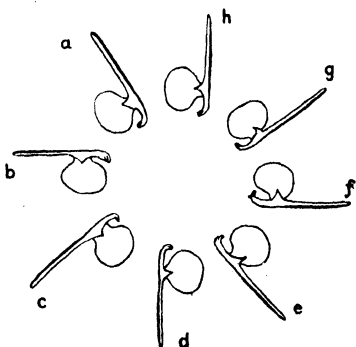


FIG. 48

on the right-hand side of the figure, when acted on by gravity, must be pulled in such a way that the outer side of the root-tip (that drawn with the thickened line) is in every case pulled down. On the other hand, the root, when on the left side, is affected in such a way that the inner side of the tip (that drawn with a thin line) is pulled down. If then the seedling can be arranged so that it takes up each position for the same length of time, the net result, due to any attraction that gravity may have for it, will be nil.

The simplest way to achieve this is to make the seedling revolve slowly and evenly by means of some clock-

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work mechanism. An apparatus of this kind is called a Klinostat.

To make a simple Klinostat.—A cheap clock can easily be converted into a klinostat.

The minute-hand must be removed, as it is not required, and will be found to be in the way if it is not cut off. A thin rod, about four inches long, is then attached to the axis of the hour-hand so that it projects horizontally from the axis.

As the hour-hand revolves the attached horizontal rod must necessarily revolve with it, and to this rod can be attached the seedling that is to be experimented with.

EXPERIMENT 62

Aim.—To find out whether the downward growth of the root is caused by the attraction of gravity.

Method.—A pad of damp moss is wrapped round the end of the klinostat rod and kept in position by a rubber band. Care must be taken that the moss is

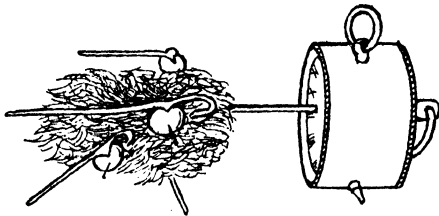


FIG. 49

made secure, otherwise it will slip and not revolve with the revolution of the rod.

Some germinating peas are fastened to the pad by means of pins.

The clock is wound up and set under a bell-jar.

Observations.—The root does not grow downwards, but continues to grow in whatever direction it was placed on the damp pad.

The shoot also continues to grow in the direction in which it is placed and does not turn upwards (Fig. 49).

Inferences.—The direction of growth of both the root and the shoot is influenced by gravity. In the case of the root the influence is a positive one, the root being attracted towards the centre of the earth; the influence is negative in the case of the shoot.

Geotropism is the term used to denote the way in which the plant reacts in response to the stimulus exerted by gravity. The main root is said to be positively geotropic, since it grows towards the earth's centre. Shoots, on the other hand, are negatively geotropic.

EXPERIMENT 63

Aim.—To show the curves taken by the root and shoot in response to gravitational stimulus.

Method.—A broad-bean is suspended over a gas-jar of water and left to germinate. When the main root has reached almost to the bottom of the jar and the lateral roots are well developed the mouth of the jar is closed with a cork. This can be done by boring a hole in the cork large enough to fit the top of the root and then cutting the cork into two pieces. The cork is made secure with paraffin or plasticine. The apparatus is then inverted (Fig. 50).

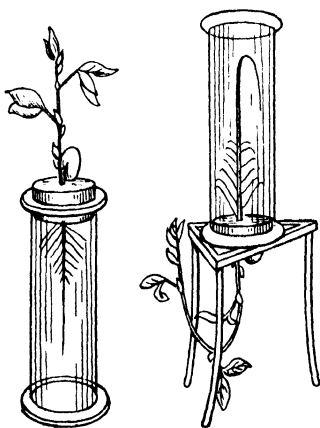


FIG. 50

Observations.—The shoot curves and continues its growth vertically upwards.

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The primary root bends over and grows vertically downwards.

The lateral roots turn obliquely downwards.

EXPERIMENT 64

Aim.—To find out what part of the root is sensitive to gravity.

Method.—Two broad-bean seedlings with radicles of about one to two inches long are fixed to a strip of

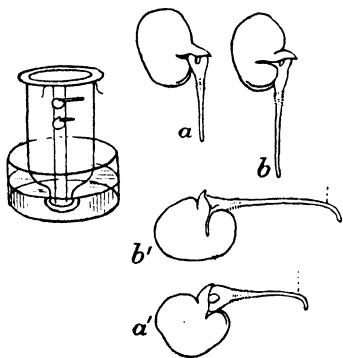


FIG. 51

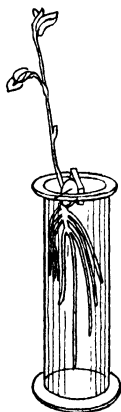


FIG. 52

sheet cork and suspended in a damp atmosphere with their radicles in a horizontal position.

The strip of cork may be suspended by means of cotton in an inverted bell-jar standing in a dish of water. A greased glass-plate can be put over the base of the jar so that the air within may be kept damp (Fig. 51).

The seedlings are drawn carefully before being attached to the cork (Fig. 51, *a* and *b*).

They are again drawn after twenty-four hours (*a'* and *b'*).

Observations.—The tips of both seedlings have turned downwards.

By measuring off on the seedlings *a'* and *b'* the length of the radicles of the seedlings *a* and *b*, it is seen that the downward curve has begun in both cases just behind the point which marks the position which the root-tips occupied when placed on the cork.

Inferences.—The root-tip and region immediately behind it is sensitive to gravity. The remainder of the root is unaffected by gravitational stimulus.

EXPERIMENT 65

Aim.—To find out what provision the plant makes against injury of the primary root.

Method.—A broad-bean seedling with a radicle of about an inch long is selected. The growing part of the radicle is cut off. The seedling is then suspended over water in a gas-jar with part of the radicle dipping down into the water. The gas-jar is covered with black paper.

Observations.—The seedling is not killed by the removal of the growing part of the radicle. Very soon secondary roots are given off from the radicle. Generally, but not invariably, one of the secondary roots grows vertically downwards and in this way functions as the primary root (Fig. 52).

Inference.—One of the secondary roots which would normally grow horizontally usually takes a vertical position if the primary root becomes injured.

EXPERIMENT 66

Aim.—To find out what provision is made, in some plants at any rate, against injury to the primary shoot.

Method.—Two broad-beans are planted in a pot. From one of the seedlings the shoot is cut off as soon as it comes through the soil.

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Observations.—In a few days the damaged seedling produces two new shoots which emerge from the ground by the side of the cut stem (Fig. 53). On taking this seedling out of the earth and examining it, the two

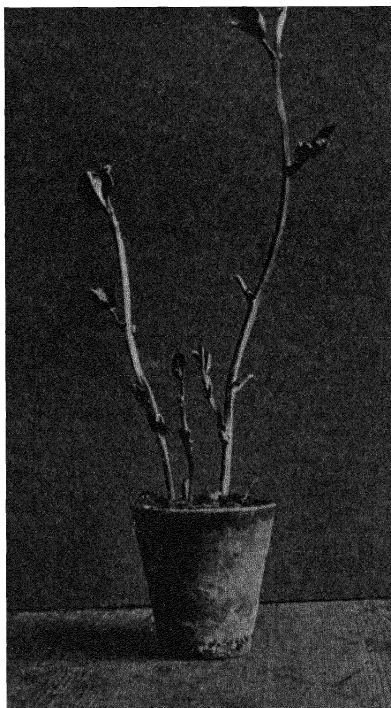


FIG. 53

shoots are seen to be borne in the axils of the cotyledons.

Inference.—In the broad-bean, buds are borne in the axils of the two cotyledons. These buds usually remain dormant, but they have power to develop should the primary shoot be injured.

EXPERIMENT 67

Aim.—To find out in what part of the root growth takes place.

Method.—A broad-bean seed germinates in damp sawdust or fibre. When the root measures about one and a half inches the seedling is removed from the sawdust, carefully washed and dried with blotting-paper. The root is then marked by horizontal lines

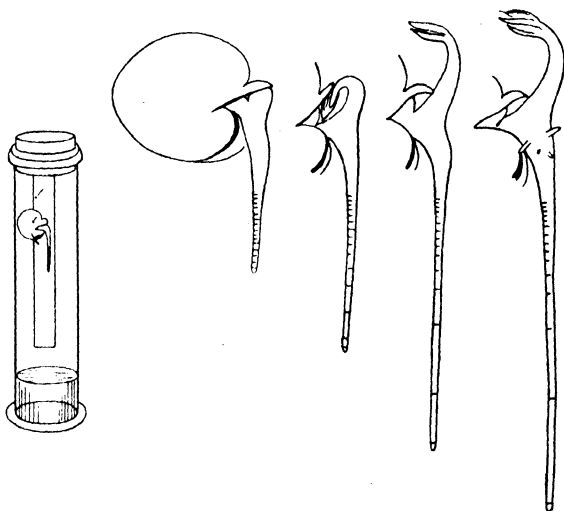


FIG. 54

into one millimetre divisions (1 mm. = $\frac{1}{25}$ inch approximately). The marks are made with Indian ink by means of a small camel's-hair paint-brush. The ink will not run if the root is properly dried. It will be sufficient if a length of fifteen millimetres from the tip is measured off.

The seedling is then pinned to a strip of sheet cork which is fitted into the cork of a gas-jar as described in Experiment 56.

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At intervals of twenty-four hours the seedling is carefully sketched.

As the Indian ink marks tend to get blurred it is well to re-mark them frequently.

Observations.—In Fig. 54 are given drawings of a bean-seedling made at intervals of twenty-four hours.

On the first day fifteen equal lengths of one millimetre were measured off from the tip.

After twenty-four hours it was seen that no growth in length had taken place in the division nearest the tip nor in the five divisions furthest from it, whereas the greatest growth had taken place in the third and fourth divisions from the tip.

The next reading showed that the second and third divisions only were still growing in length, the fourth division and those above it had ceased elongating.

In the final reading taken growth was confined to the second division.

It was also observed that the root continued to grow in thickness after it had ceased to grow in length.

Inferences.—A root does not grow in length at the tip but in the region immediately behind the tip.

The elongating region is very short, extending only, in the case of the bean, for a distance of about ten millimetres.

The region of greatest elongation is about three millimetres from the tip.

Each part of the root in turn very soon reaches its maximum length.

Any part of the root continues to grow in thickness after ceasing to grow in length.

EXPERIMENT 68

Aim.—To find the connection between the growing part of the root and the region that is sensitive to gravity.

Method.—A broad-bean seedling having a radicle whose length is about one and a half to two inches

long is selected. The tip of the root for a distance of fifteen millimetres is then divided off into millimetre lengths by means of Indian ink as described in Experiment 67.

A strip of sheet cork is cut having a length equal to the diameter of a crystallizing dish or other glass vessel. The seedling is pinned to the strip of cork. Water is put into the glass vessel and the strip of cork then fixed above the water so that the root of the seedling lies horizontally (Fig. 55).

Observations.—Within twenty-four hours the tip of the root is found to have turned vertically downwards.

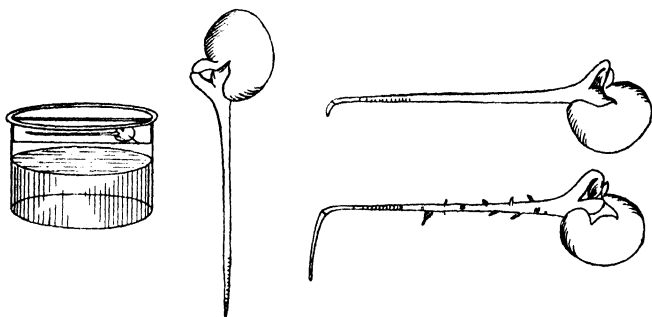


FIG. 55

The part at which the curve has taken place is the region of the greatest growth. That part of the root which has ceased growing remains horizontal.

Inferences.—Gravitational stimulus is operative only on the growing portion of the root; and when placed in a horizontal position the radicle curves downwards, the point of curvature being the region of greatest growth.

EXPERIMENT 69

Aim.—To find out in what part of the shoot growth takes place.

Method.—Any rapidly growing plant can be used for

this experiment. A sunflower or broad-bean seedling answers well. The upper part of the stem, for a distance of about ten centimetres from the apex, is marked off by transverse lines into lengths of five millimetres each. The marks can be made with Indian ink by means of a small camel's-hair brush.

Fig. 56 (a) is a drawing on a reduced scale of a broad-bean seedling, the actual length of whose stem at the beginning of the experiment was about twenty-five centimetres. A length of ten centimetres from the tip was marked off into five millimetre divisions. Fig. 56 (b) shows the lengths of the measured portion of the stem on the first, second, sixth, and tenth days, the scale to which the figure is drawn being three-quarters of the actual lengths measured.



(FIG. 56 a)

Observations.—In the case of the broad-bean seedling observed it was found:

1. That growth in length took place through a distance of about 4.5 centimetres from the apex.

2. That all the growing part does not elongate at the same rate; the region of maximum growth changes its position from day to day, keeping at a distance of about 1.5 centimetres from the apex.

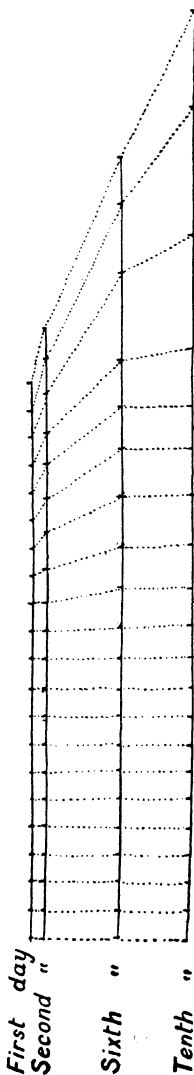


FIG. 56 (b)

Inference.—The stem of a plant continues to grow a length throughout a much longer distance than is observed in the case of the root (Experiment 67).

The increase in length is most rapid at a point at some little distance behind the apex.

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